WT-1445 (EX)
EXTRACTED VERSION

OPERATION PLUMBBOB

Technical Summary of Military Effects, Programs 1-9

Defense Atomic Support Agency
Sandia Base, Albuquerque, New Mexico

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Nevada Test Site
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NOTICE

This is an extract of WT-1445, Operation PLUMBBOB, Technical Summary of Military Effects, Programs 1-9, which remains classified SECRET/RESTRICTED DATA as of this date.

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Director
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FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

This report has been reproduced directly from available copies of the original material. The locations from which material has been deleted is generally obvious by the spacings and "holes" in the text. Thus the context of the material deleted is identified to assist the reader in the determination of whether the deleted information is germane to his study.

It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.

ABSTRACT

A considerable part of the overall effort of the 45 projects in the military-effect program was concentrated on Shot Priscilla, since this was a device of known yield and was designated as the Department of Defense (DOD) shot. One of the primary objectives of the program was to obtain data on the loading and response of structures, documenting blast and shock phenomena in the higher pressure regions (above 50 psi). Shot Smoky presented the opportunity to study the effects of terrain on blast and shock phenomena, another major objective. Also among the primary objectives was the study of neutron-induced activity in soils. This study, together with studies of the electromagnetic (EM) signal generated by the detonation, was made primarily on shots with relatively little or no shielding. Another important objective was to obtain data on delivery criteria (nuclear and blast inputs) for the F-89D aircraft in delivering an MB-1 rocket. The final major objective called for obtaining data on the effects of nuclear weapons on a variety of military equipment and on a large biological specimen (swine).

In Program 1 (blast and shock measurements) airblast data at ground ranges as close as 350 feet was obtained. Unfortunately, electronic measurements at ground zero were lost, presumably because of the induction signal.

Measured values of acceleration agree with predictions between the surface and a depth of 10 feet but remain constant (or increase) between 10 and 30 feet; below 30 feet, values again agree with predictions. The consistently high values between depths of 10 and 30 feet are believed to have been caused by inhomogeneities in the soil.

Surface vertical displacement produced by the blast wave was about 14 inches at an incident overpressure of 270 psi, 6 inches at 200 psi, 3 inches at 100 psi, and 2 inches at 60 psi.

In the studies of terrain effects, the data showed that (1) measured pressure values on the flat (control) terrain line agree with predictions; (2) overpressures on front slopes of high ridges are higher than those on flat terrain at corresponding distances, whereas back slope pressures are lower; (3) overpressures on low, rolling terrain are higher than those on flat terrain for like ground distances, and dynamic pressures are lower; (4) dynamic pressures on front slopes of high ridges are lower than those on flat terrain at corresponding distances, and on back slopes they fall sharply below those on flat terrain; and (5) the waveforms on all front slopes have a smaller rise time than that for corresponding waveforms on the flat terrain line, waveforms on the back of slopes are very nearly ideal, and waveforms on the low, rolling terrain line do not show a strong precursor.

Strong precursors were formed during all balloon shots, but four out of five tower shots showed little evidence of a precursor, suggesting that precursor formation is inhibited by tower shielding.

In Program 2 (nuclear radiation) the results of the studies showed that neutron-induced soil activity is a definite tactical hazard at early times. The induced activity was found to be generated primarily by thermal neutrons, although epithermal and even fast neutrons contribute. The effect of increased moisture was to increase the intensity of the fields, although the effect was not as critical as had been expected. The data indicates that, at H + 1 hour, a foot soldier crossing the ground-zero area of a weapon of the Shot Owens type detonated at 500 feet over Nevada-type soil would accrue no more than 200 r. If the crossing were delayed until H + 10 hours, a dose of about 40 r would be sustained.

As a result of the initial-gamma measurements, it was learned that, over the first 5-second interval for which data was obtained, the total gamma dose gradually increases with height aboveground, to reach a value 30 percent greater at an altitude of 400 feet relative to the corresponding ground measurement. There was no further increase up to 950 feet.

Results indicate that an MB-1 rocket can be fired from an F-89D interceptor aircraft at an altitude of 19,000 feet mean sea level with a gamma dose to the crew of less than 3 r.

In Program 3 (effects on structures) it was found that the numerous underground structures sustained less damage than predicted. It was also shown, confirming theory, that underground arch-type shelters are efficient structurally to withstand surface air overpressures up to 200 psi. For the underground structures tested, it was found that a minimum of 5 feet of earth cover is required to provide sufficient radiation shielding from a 36.6-kt device.

The aboveground dome structures sustained somewhat greater damage than anticipated. The results added to the existing loading and response data of aboveground reinforced concrete dome and arch structures. The test generally confirmed existing theory and model shock-tube data, which indicate that, for aboveground protective construction, the dome is an efficient type of structure for use in higher overpressure regions (up to about 70 psi) whereas the arch is inefficient structurally in resisting high-drag loadings.

Program 4 (biomedical effects) found in the exposure of some 1,200 pigs during Shots Franklin, Wilson, and Priscilla that the LD_{50-30} is about 486 rep gamma rays plus neutrons, based on data obtained on the unshielded line of Shot Wilson. This LD_{50-30} dosage compares favorably with data from project laboratory experiments, but it is considerably higher than the 230 r based on data from Operation Greenhouse.

The main effort was during Shot Priscilla, where 710 pigs were in the open and subjected to the effects of the detonation. Because of the small number of wounds of the type desired, the evaluation of the medical and surgical treatment did not produce definitive results. However, certain conclusions appear valid: (1) For a large biological specimen in the open, within the precursor from a nuclear weapon, the primary cause of death is mechanical injury to the organisms due to translation, and nearly 100 percent are killed instantly. (2) Outside the precursor (during Priscilla the precursor formed at a distance of 450 to 550 feet from ground zero and extended out to approximately 4,000 feet) temporary survival may be expected in the open, barring total missile injury, but the radiation levels at these ranges are so great that early death will invariably ensue. (3) Close-in foxholes (for Priscilla they were at 2,730 feet and 3,000 feet from ground zero) may provide sufficient protection to prevent total injury from blast and burn, but the radiation shielding is inadequate, and a lethal dose of radiation will ultimately be the cause of death, with slightly longer survival time.

Two groups of swine that had received superlethal dosages of 1,440 and 1,270 rep, respectively, of body radiation were given intravenous transfusions of a mixture of cells from spleen and bone marrow. Post mortems of these animals gave no evidence of regeneration of the bone marrow.

In Program 5 (effects on aircraft structures) the final analysis of data shows that the objectives of the various aircraft studies were accomplished, except for the airship project.

The two overpressure-prediction methods gave results that varied slightly from the results obtained. Attempts to correlate second shock data were not conclusive.

Analysis of data indicates that the crushing effects of overpressure will be limiting for the HSS-1 helicopter. The delivery capability of the HSS-1 helicopter for nuclear antisubmarine weapons can be defined, provided sufficient information is available to accurately predict the free-air effect field from underwater detonations.

Under the test conditions experienced by the ZSG-3 airship, the car structure and suspension system appeared to be satisfactory strengthwise, but tail-assembly movable-surface stops may receive damage from shock-wave forces on the control surfaces. For the free-flight condition, the envelope and ballonet response to shock inputs appeared to be the critical element in the airship system. Primarily because of operational difficulties in the field, the scope of data obtained was not adequate to satisfy the basic objectives of the project.

The critical response of the FJ-4 structure was determined to be bending at Wing Station 17.5. Good correlation was obtained between measured and analytical structural data for the FJ-4 for the low-yield weapons, but methods for predicting thermal inputs were not satisfactory.

Sufficient data was obtained to confirm the delivery capability of the A4D-1 for low-yield weapons.

The dynamic response to blast for the F-89D produced higher wing loads than predicted analytically in the capability study. The significant F-89 structural loads resulted only from the gust associated with the shock wave; thermal and diffraction effects were so small as to be unimportant. Incremental dynamic loads were not affected by the magnitude of maneuvering loads existing on the structure of the F-89 at shock arrival.

In Program 6 (test of service equipment and EM effects) the following results were obtained from the six projects involved

The mine clearance study determined that (1) the procedures for predicting mine actuation under nuclear detonations were reasonably accurate; (2) sympathetic actuation in the live mine fields occurred, indicating the extension of clearance under nuclear blast effects; (3) mine response under nuclear blast effect increases with burial depth to between 6 and 9 inches and then decreases at greater depths, (4) the pressure-actuated devices, High Hat and Partner, provided significantly improved protection at high overpressures, but the Partner design was questionable at pressures below 16 psi; and (5) the three influence-type fuzes tested proved to be relatively invulnerable to a nuclear detonation.

Results of the project to measure EM effects show that the magnetic field component in the close vicinity of a nuclear detonation (1) consists of a field rising to an initial peak in a few microseconds and decaying to zero in less than 100 μsec as well as a field of considerably longer duration, which rises to a peak in a few milliseconds and decays over much longer periods; (2) has its major component in a horizontal plane with maximum peak amplitudes of the order of 10^3 amp-turns/m at distances less than 1,000 meters; (3) has radial and vertical components whose amplitudes are generally smaller than the major component; and (4) has rise times such that maximum time derivatives of the fiels are of the order of 10^8 amp-turns/m-sec.

The study of the effects of nuclear radiation on transistors and semiconductor diodes showed that components in operating equipment suffered permanent damage comparable to those passively exposed. Both transistors and semiconductors exhibited degradation of performance depending upon the total integrated neutron flux to which exposed

The study concerning the attenuation of EM radiation through an ionized medium found no attenuation of radio and radar signals, for any of the test frequencies employed, as a consequence of passage through the nuclear cloud.

The investigation of a system to indirectly detect and locate nuclear weapon strikes obtained lines of position that gave fixes with an average error of 0.8 naut mi. In general, the times of detonation were established with an error of less than 10 msec. It was found that there were no consistent patterns peculiar to the waveforms, field intensities, or pulse durations of lightning transients that would distinguish them from the EM pulse of a nuclear detonation.

In Program 8 (thermal radiation measurements and effects) the three hot-weather uniform ensembles tested did not withstand the thermal-input energies of interest to the Continental Army Command. Although a certain amount of protection was achieved in these experimental uniforms because of their ability to retard flaming, not one of them would survive in condition to be reusable.

Flaming of materials was the most startling effect noted during the Plumbbob tests. The extent and severity of burns on the animals from this cause far exceeded those from radiant burns.

A plastic skin simulant was tested in six basically different configurations. The results show that laboratory methods employing the carbon-arc thermal radiation source are adequate.

Data obtained from materials exposed to Shot Priscilla indicated that laboratory methods for studying ignition of cellulose materials would yield qualitative data that was within 25 percent of expected field data.

Results show that the data obtained by the thermal-radiant-exposure meter (TREM) was in general agreement with that obtained by other instruments as to the exposure level. In addition, the precision obtained by the TREM appears to be better than that obtained by the metal-foil instruments.

Improved instrumentation for making measurements inside the fireball was tested. Twenty-four out of the 25 metal and plastic instrumented spheres and cylinders were recovered. Many of the recorders jammed, thus failing to record results; however, it is felt that the state of the art of recording fireball phenomena was advanced as a result of these tests. The art of recording is not sufficiently advanced at this time to obtain usable data at a slant range of 160 feet or closer for a yield similar to that of Shot Smoky, using the instrumentation techniques employed during Shot Smoky.

Program 9 (support photography) was primarily of a support nature and consisted of a single project concerned with (1) technical photographic support of the military-effects programs, (2) documentation of the overall military-effect program and production of a military-effect motion picture, (3) documentation of the detonations for release through the Joint Office of Test Information and for historical purposes, and (4) general photographic support of DOD projects. Although some photography was lost because of unusually high pressures, which destroyed the camera stations, or unexpected radiation levels that fogged some film, the overall technical photographic effort was successful.

PREFACE

Operation Plumbbob was the first operation in which a nuclear device was suspended from a balloon for detonation and the first in which rocket-delivery of a nuclear warhead was employed. It was also the first operation during which a nuclear device was fired underground in such a way as to produce a fully contained detonation and yet allow diagnostic measurements of device performance. The last of the 24 shots in which the DOD Test Group participated was detonated 7 October 1957.

This report contains the key results obtained in the eight technical weapon-effect test programs and has been compiled by the Deputy Chief of Staff, Weapons Effects and Tests, Field Command, Defense Atomic Support Agency.

This summary report discusses overall results within a technical program, so each project is not always treated individually. However, the appendix contains a brief summary of each project.

For more detail on a particular project, and especially on such matters as background, theory, and instrumentation, which have been deliberately condensed or omitted in this report, the reader is referred to the individual project reports (WT reports). The WT reports are listed under the projects described in the appendix.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Based on information from the Atomic Energy Commission (AEC) that a nuclear test series would be conducted at the Nevada Test Site (NTS) beginning in the spring of 1957, an integrated program of military-effect tests was planned by the Chief, Armed Forces Special Weapons Project (AFSWP), (now Defense Atomic Support Agency, DASA). This program was based on a continuing study of the needs of the Armed Forces for data on the effects of nuclear weapons.

The original code name for the operation was Pilgrim, but it was changed to Plumbbob shortly before the test series began. The weapon-effect program was approved with a budget of $6,814,200 by the Assistant Secretary of Defense, Research and Development, 22 August 1956 (Reference 1). On 13 September 1956 (Reference 2), the Chief, AFSWP, directed the Commander, Field Command, AFSWP, to: (1) execute the military-effect test phases as a joint AEC-Department of Defense (DOD) endeavor; (2) coordinate military assistance and participation, in support of the AEC; (3) coordinate operational, training, and troop-observer participation; and (4) coordinate Federal Civil Defense Administration (FCDA) participation in the military-effect program.

The Commander, Field Command, AFSWP, was thus responsible for the completion of the detailed plans, administration of the technical programs, and the approval and publication of completed reports upon the conclusion of field operations. General policy and guidance for military participation in continental field tests of nuclear devices and weapons were contained in letters from the Chief, AFSWP, to Commander, Field Command (References 3 and 4).

The Commander, Field Command, represented Chief, AFSWP, as the agent of the DOD for coordination with the AEC, its contractors, and any other government agency participating in the test activities. Within Field Command, the Deputy Chief of Staff for Weapons Effects Tests (FCWT) had the responsibility for the administration of the program.

1.2 OBJECTIVES

The major objectives of the military-effect studies during Operation Plumbbob were in the following areas: (1) loading and response of structures, and blast and shock phenomena in the higher-pressure regions (above 50 psi); (2) influence of rough terrain on blast and shock phenomena and on damage effects; (3) neutron-induced activity in soils; (4) delivery critera (nuclear and blast inputs) for the F-89D aircraft in delivering an MB-1 nuclear-warhead rocket; (5) effects of a nuclear detonation on a large biological specimen (swine), and (6) effects on military equipment.

The objectives of each program are discussed in detail in the chapters devoted to the individual programs.

1.3 SUMMARY OF SHOT DATA

Yields and environmental data are presented in Tables 1.1 and 1.2. The recommended yield values in Table 1.1 are the latest available. In analyzing data, the yield values available at the time were used.

1.4 PARTICIPATION

The shots on which each project actually participated are listed in Table 1.3. The DOD military-effect program consisted of 45 projects and participated during 24 shots of the Plumbbob series. In some cases, participation varied from that planned owing to instrumentation difficulties at the time of particular shot, changes in yield or firing schedule, etc.

1.5 ORGANIZATION

During the planning phase, the military-effect program for Operation Plumbbob was implemented by the Commander, Field Command, through the staff office of FCWT. The organization of this office is shown in Figure 1.1. The FCWT staff moved to the NTS and became operational 15 April 1957. At that time, in keeping with the joint AEC-DOD concept for the conduct of the operation, this staff office was integrated into the Nevada Test Organization (Figures 1.2 through 1.4).

TABLE 1.1 SUMMARY OF SHOT DATA AND ENVIRONMENTAL CONDITIONS

Shot	Sponsor*	Date	Time ‡ PDT	TNT-Equivalent Yield				Zero-Point Environment					
				Predicted	Hydrodynamic	Radiochemical	Total Recommended	Support	Area	Coordinates (Nevada State Grid)		Elevation of GZ	Burst Height Above GZ
		1957		kt	kt	kt	kt			N	E	feet MSL	feet
Boltzmann	L	28 May	0455:00.155	~11	11.1 ± 0.6	12.2 ± 0.6	11.5 ± 0.5	Tower	7c	854,123.94	687,540.16	4,243.00	500
Franklin	L	2 Jun	0454:59.944		0.09 ± 0.01	0.135 ± 0.005	0.138 ± 0.006	Tower	3	837,026.05	666,416.41	4,024.70	300
Lassen	U	5 Jun	0445:03		0.4–4.0	0.47 × 10^{-3} ± 5 pct	0.47 × 10^{-3} ± 5 pct	Balloon	9a	866,633.00	682,418.00	4,214.46	500
Wilson	U	18 Jun	0445:00.204	8	9.4 ± 5 pct	10.3 ± 5 pct	10.3 ± 0.5	Balloon	9a	866,633.00	682,418.00	4,214.46	500
Priscilla	A	24 Jun	0630:00.122	40	36.3 ± 1.1	37.1 ± 1.8	36.6 ± 1	Balloon	FF	746,249.98	716,000.29	3,076.00	700
Hood	U	5 Jul	0440:00.062	60–70	70.6 ± 1.8	74.1 ± 5 pct	71 ± 2	Balloon	9a	866,633.00	682,418.00	4,214.46	1,500
Diablo	U	15 Jul	0430:00.057	11–13	18.8 ± 1.0	16.7 ± 1.6	17.0 ± 1.0	Tower	2b	874,146.13	662,634.17	4,466.92	500
John	A	19 Jul	0700:04.6 ± 0.5	~1.7	—	1.73 ± 0.1	1.73 ± 0.1	MB-1 Rocket	†	877,939 ± 16	676,838 ± 10	4,280	14,830 ± 5[illegible]
Kepler	L	24 Jul	0449:59.931	11	10.7 ± 0.6	10.3 ± 0.5	10.3 ± 0.5	Tower	4	854,233.66	664,463.68	4,307.60	500
Owens	U	25 Jul	0629:59.686	2–10	9.4	9.6 ± 5 pct	9.7 ± 0.5	Balloon	9a	866,633.00	682,418.00	4,214.46	500
Stokes	L	7 Aug	0525:00.1708	10–20	19.8 ± 1	18.5 ± 0.9	19 ± 1	Balloon	7b	851,124.60	687,533.17	4,186.45	1,500
Shasta	U	18 Aug	0459:59.963	11–13	22.4 ± 1.0	16.8 ± 5 pct	16.5 ± 1.0	Tower	2a	866,030.03	663,322.51	4,382.35	500
Doppler	L	23 Aug	0530:00.094	~12	10.7 $^{+0.7}_{-0.5}$	10.7 ± 0.3	10.7 ± 0.3	Balloon	7a	851,124.60	687,533.17	4,186.45	1,500
Franklin Prime	L	30 Aug	0539:59.8535 ± 0.0003	~2	4.75 ± 0.25	4.61 ± 0.4	4.7 ± 0.3	Balloon	7b	851,124.60	687,533.17	4,186.45	750
Smoky	U	31 Aug	0529:59.9842 ± 0.0005	45	44.9	43.71 ± 5 pct	44 ± 1	Tower	2c	867,690.00	674,450.00	4,479.12	700
Galileo	L	2 Sep	0540:00.0259 ± 0.0003	~11	10.25 ± 1.7	11.3 ± 0.6	11.1 ± 1	Tower	1	838,780.31	644,588.64	4,236.00	500
Wheeler	U	6 Sep	0544:59.979 ± 0.0003		0.163 ± 0.009	0.195 ± 5 pct	0.197 ± 0.01	Balloon	9a	866,633.00	682,418.00	4,214.46	500
LaPlace	L	8 Sep	0559:59.7872 ± 0.0003	~2	1.25 ± 0.06	1.22 ± 0.06	1.22 ± 0.05	Balloon	7	851,124.60	687,533.17	4,186.45	750
Fizeau	L	14 Sep	0944:59.837 ± 0.001	~10	10.6 ± 0.8	11.1 ± 1	11.3	Tower	3b	831,773.33	685,427.46	3,997.40	500
Newton	L	16 Sep	0549:59.8573 ± 0.0002		10.6 ± 0.8	12.2 ± 0.5	11.6 ± 0.6	Balloon	7b	851,124.94	687,540.14	4,186.45	1,500
Rainier	U	19 Sep	0959:59.454 ± 0.002	1.6	—	—	1.7 ± 0.2	Underground	12b	890,571.02	635,003.48	6,611.43	—
Whitney	U	23 Sep	0529:59.798 ± 0.001	15	23.1 ± 0.65	19.2 ± 5 pct	18.5 ± 0.9	Tower	2	869,823.20	660,103.03	4,466.50	500
Charleston	U	28 Sep	0559:59.9422 ± 0.0003	10–100	10.9 ± 0.4	11.5 ± 5 pct	11.5 ± 0.5	Balloon	9a	866,633.69	682,416.34	4,214.97	1,500
Morgan	U	7 Oct	0500:00.0528 ± 0.003 §	2–5	7.66 ± 0.23	7.8 ± 5 pct	8.0 ± 0.04	Balloon	9a	866,633.69	682,418.34	4,214.97	500

* U: UCRL; L: LASL; A: AFSWP.
† Over Yucca Flat.
‡ Uncorrected for WWV transit time.
§ Standard time.

TABLE 1.2 METEOROLOGICAL CONDITIONS AT YUCCA FLAT WEATHER STATION

Shot	On Surface (3,924 feet MSL)						At Approximate Elevation of Ground Zero MSL						At Approximate Height of Burst MSL					
	Atmospheric Pressure	Free Air Temperature	Dew Point	Relative Humidity	Wind Condition Direction	Wind Condition Velocity	Atmospheric Pressure	Free Air Temperature	Dew Point	Relative Humidity	Wind Condition Direction	Wind Condition Velocity	Atmospheric Pressure	Free Air Temperature	Dew Point	Relative Humidity	Wind Condition Direction	Wind Condition Velocity
	mb	°C	°C	pct	deg. true	knots	mb	°C	°C	pct	deg. true	knots	mb	°C	°C	pct	deg. true	knots
Boltzmann	879	12.6	3.6	50	Calm		868	18.1	4.6	41	Calm		846	21.5	3.6	31	Calm	
Franklin	881	11.6	2.7	49	Calm		878	14.0	3.0	47	Calm		876	20.0	7.3	48	Calm	
Lassen	881.6	17.8	4.1	40	Calm		873	23.3	8.6	40	230	2	866	27.2	9.0	33	230	8
Wilson	884	12.0	−1.0	40	337	4	882	17.0	2.6	36	360	5	865	30.3	3.2	22	020	6
Priscilla*	—	—	—	—	—	—	909.5	17.5 ± 1	−0.6	29	Calm		866.7	24 ± 2	−0.2	20 ± 2	Calm	
Hood	881	14.0	−7.2	24	Calm		876	21.0	−3.3	19	Calm		821	26.9	−3.6†	15†	200	4
Diablo	881	12.8	−0.2	24	Calm		864	23.1	−0.6	30	230	8	840	23.6	−0.3	30	230	4
John	881	20.6	1.0	27	Calm		869	22.1	1.3	25	180	5	500	−9.7	—	—	210	14
Kepler	880	9.3	−8.1	26	Calm		865	21.0	−5.0	22	360	1	850	21.2	−2.5	30	010	2
Owens	878	16.6	−6.6	21	Calm		871	20.0	−3.6	20	310	2	854	23.1	−0.6	20	310	3
Stokes	880	8.1	−10.7	28	Calm		876	16.8	−4.8	23	200	1	784	15.6	−1.5	25	140	6
Shasta	883	17.2	3.3	28	Calm		866	26.4	8.9	33	200	4	852	26.5	8.0	31	200	4
Doppler	882	19.0	11.2	60	Calm		877	21.4	13.9	57	Calm		832	22.0	10.4	48	Calm	
Franklin Prime	878	8.2	−8.2	36	Calm		868	11.0	−3.1	36	340	1	844	14.3	6.2	38	340	2
Smoky	883	4.2	−11.2	31	Calm		856	14.0	−2.6	31	Calm		844	15.2	−1.2	28	Calm	
Galileo	887	6.5	−7.1	32	Calm		878	15.8	−1.6	30	Calm		862	16.8	−0.8	27	Calm	
Wheeler	886	14.6	−3.6	28	Calm		876	20.0	−1.1	25	340	2	861	23.8	2.3	24	360	3
LaPlace	880	13.5	−1.5	36	Calm		874	19.0	1.2	30	260	2	849	25.4	1.7	21	260	3
Fizeau	882.8	25.4	−1.2	17	Calm		880	26.1	−1.5	17	Calm		865	22.0	−2.0	18	Calm	
Newton	878	5.0	−11.9	25	200	1	862	13.2	−6.8	27	200	1	820	17.8	−5.3	20	200	6
Rainier	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Whitney	885	4.5	−9.8	34	Calm		867	18.1	−3.7	26	Calm		851	17.0	−3.7	28	Calm	
Charleston	884	14.0	−3.4	29	Calm		876	16.1	0.9	31	180	2	829	18.5	1.7	32	180	6
Morgan	879	−0.1	−12.1	40	Calm		868	7.3	−5.9	38	360	3	854	11.9	−6.0	30	350	7

* These measurements were reported from a Frenchman Flat Weather Station.

† Estimated.

TABLE 1.3 PROJECT PARTICIPATION

	Boltzmann	Franklin	Lassen	Wilson	Priscilla	Hood	Diablo	John	Kepler	Owens	Stokes	Shasta	Doppler	Franklin'	Smoky	Galileo	Wheeler	LaPlace	Fizeau	Newton	Ranier	Whitney	Charleston	Morgan			
1.1		■		■	■	■		■	■	■	■	■				■											
1.2									■	■																	
1.3					■																						
1.4					■																						
1.5					■																						
1.7					■																						
1.8a, b, c															■												
1.9											■				■					■		■	■				
2.1		■	■	■	■					■																	
2.2				■		■				■								■									
2.3		■	■	■	■	■		■		■					■			■									
2.4		■	■	■	■	■				■																	
2.5	■	■	■	■		■		■		■																	
2.6		■	■	■	■	■																					
2.7	■		■	■	■	■	■		■	■																	
2.8				■	■	■	■																				
2.9								■																			
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* Partially funded and coordinated with DOD; administrated by CETG.

■ Indicates participation.

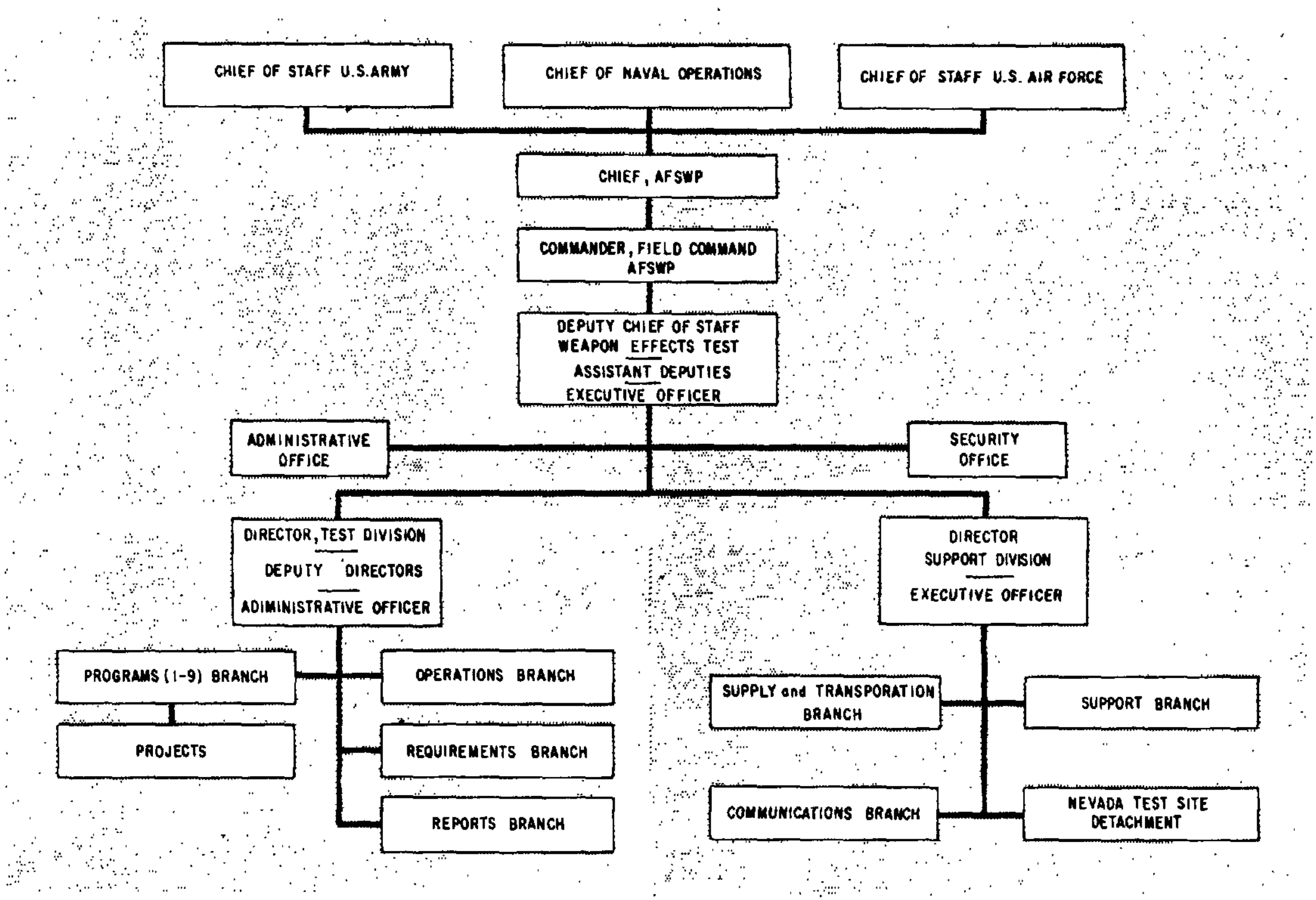


Figure 1.1 Organization of the Office of the Deputy Chief of Staff, Weapons Effects Tests, and its relation to the Chiefs of Staff.

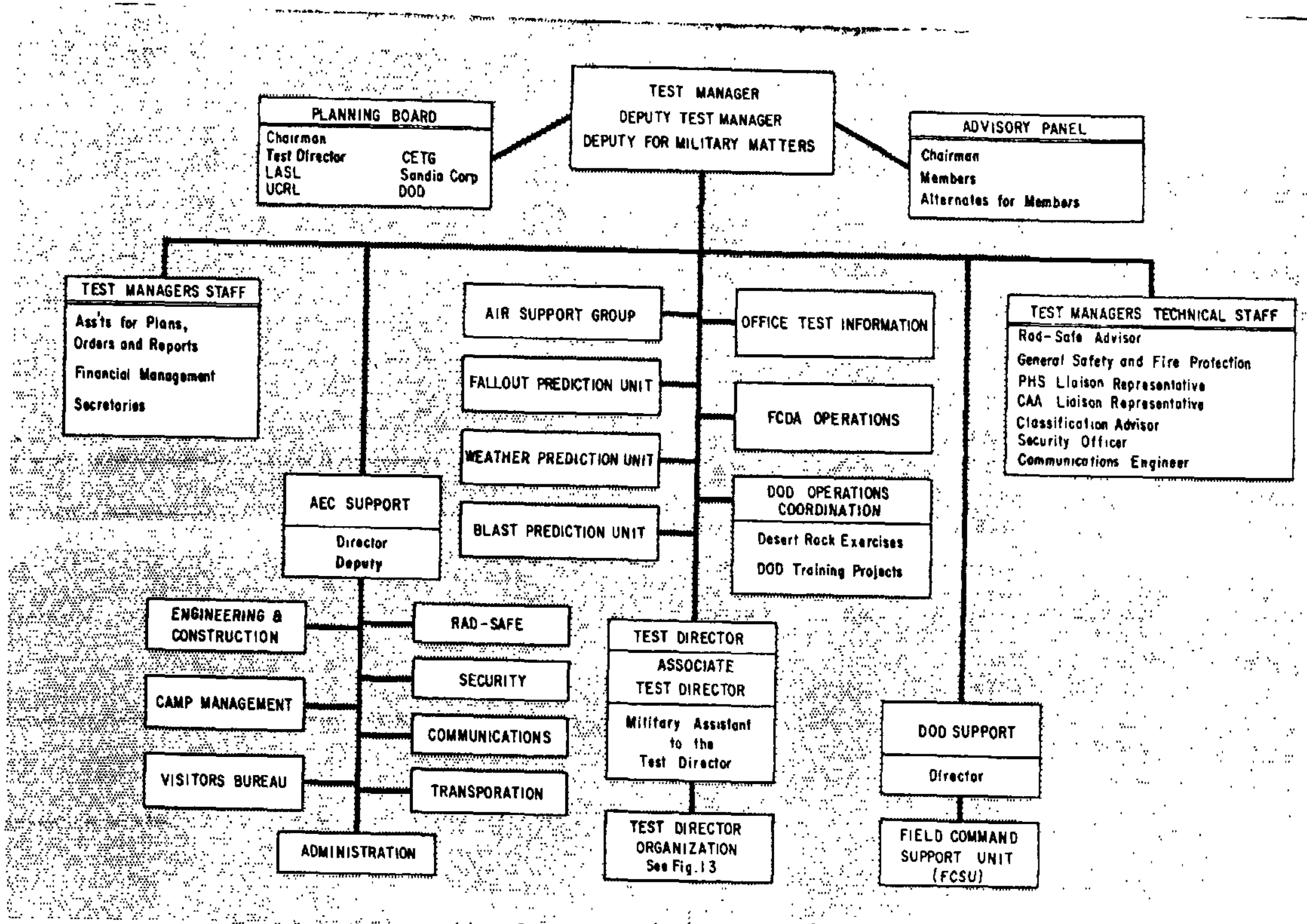


Figure 1.2 Test Manager's Organization, Nevada Test Organization.

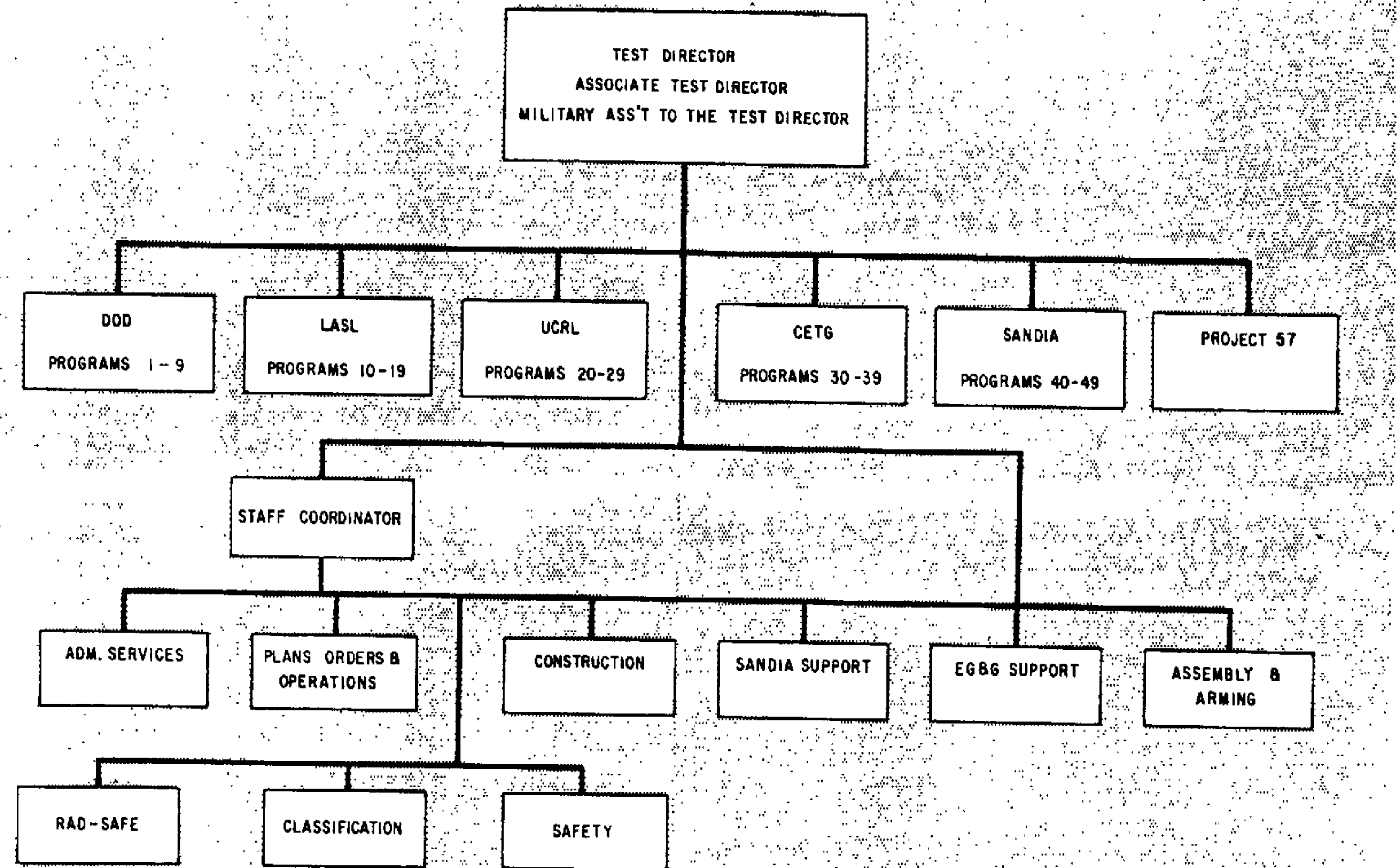


Figure 1.3 Test Director's Organization, Nevada Test Organization.

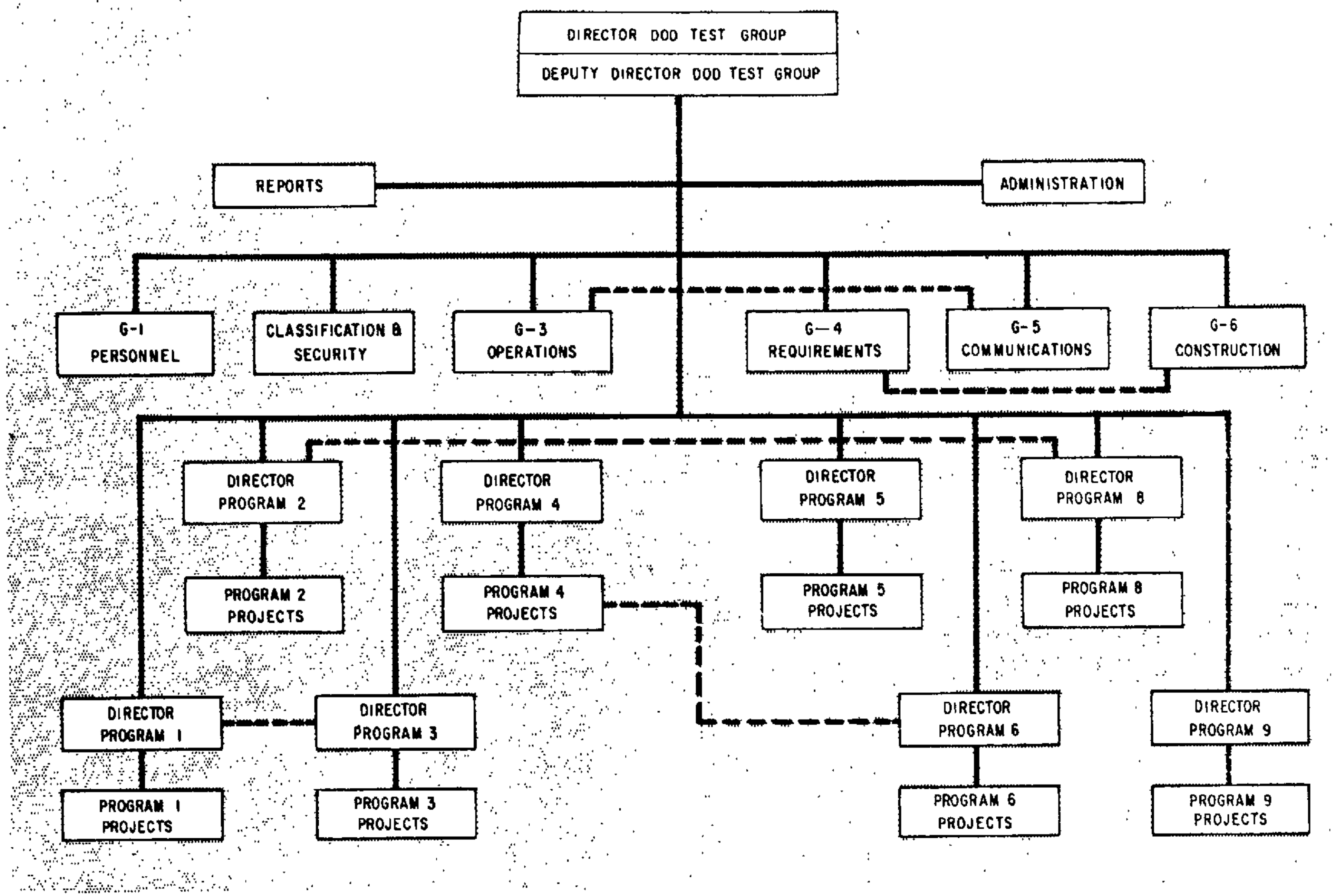


Figure 1.4 DOD Test Group, Nevada Test Organization. Dotted lines indicate alternates.

Chapter 5

BIOMEDICAL EFFECTS

The effort of Program 4, consisting of three projects, was designed to: (1) furnish information on the effects of nuclear weapons on large biological specimens (swine), (2) evaluate the eye protection afforded by an electromechanical shutter, and (3) evaluate the casualty effect of missiles translated by a nuclear detonation. To evaluate the biological effect of nuclear weapons, swine were systematically exposed to Shots Franklin, Wilson, and Priscilla. Eye-protective devices were evaluated by the exposure of rabbits and human volunteers to Shots Boltzmann, Wilson, Priscilla, Hood, and Diablo. The major missile-effects data was obtained from Shots Priscilla and Smoky.

5.1 BACKGROUND

It is often difficult to extrapolate from a physical measurement to a predicted biological response without considerable experience in correlation of these responses. Some effects of nuclear weapons have been observed in humans since 1945; but, with the development of tactical formations and civil-defense planning involving nuclear weapons, there is a requirement for further analysis of weapon effects. In the absence of experimentation on man, the investigation must utilize animals approximating man both in physiology and in response to trauma.

After exhaustive tests of various animals, considering availability, handling, and adaptability, the pig was selected as the one most suitable for this investigation, and 1,200 swine were obtained from a single breeder. To treat the nuclear casualties, a field hospital was built at the Nevada Test Site (NTS).

During Operation Redwing, it was learned that electromechanical shutters would protect rabbits' eyes from chorioretinal burns. Although no permanent damage to the eye may result from exposure to the bomb flash, there may be a temporary loss of vision (flash-blindness). Visual acuity returns to normal only subsequent to the dissipation of the after-images and readaptation of the retina to the previous level of illumination. This could require a length of time of such magnitude that a pilot would lose control of an aircraft, or something equally serious would result. Therefore, human volunteers were required to determine the duration of temporary blindness of personnel exposed to the bomb flash while being protected by mechanical shutters.

During Operation Teapot, a study was conducted inside a house, on the effects of glass missiles resulting from broken windows. It was found that the greatest casualty effect occurred from glass missiles when windows were subjected to an overpressure of approximately 3.8 psi. Since this would not be indicative of combat conditions, it was desirable to obtain information on the velocities of various battlefield debris and glass when subjected to a nuclear detonation.

5.2 PROCEDURE AND RESULTS

5.2.1 Biological Specimens. The project for determining the effects of a nuclear detonation on a biological specimen was broken down into several subtasks. The main objectives were to: (1) attempt field surgical correction of injuries in the pig, (2) investigate the effects of combined injuries at supralethal to nonlethal ranges, (3) derive the LD_{50-30} (midlethal dose in 30 days) for a large biological specimen, and (4) obtain information on missile injuries in a biological specimen.

To accomplish these objectives, 710 swine were exposed in 11 stations during Shot Priscilla. Stations ranged from 2,630 to 9,490 feet from ground zero as listed in Table 5.1. Also, 270 swine were exposed to Shot Franklin to meet Objective 3, above. Because of the unexpectedly low yield of Shot Franklin, this phase was repeated during Shot Wilson. It was planned that the animals would be exposed to between 100 and 800 rep total dose during Wilson, but results indicated that much higher doses were actually received.

The results of surgical correction of wounds after Shot Priscilla were not conclusive. The wounded animals that survived surgery had received such levels of irradiation that their course of death was similar to that of animals that had not been wounded but had been irradiated. Animals that received severe missile wounds from glass would have died from irradiation anyway. At Station 8, there was only one case of a wound directly contributing to death. Severe missile injuries were experienced, however; some 60 animals were evacuated from the exposure stations with either intraperitoneal contents extruded or a diagnosed, penetrating, abdominal or thoracoabdominal wound. However, because of the heat, dust, and cannibalization of severely wounded animals by those less severely wounded, only 19 of the expected 100 animals were evacuated from the triage station for the medical and surgical treatment study.

Many of the animals received serious thermal burns. At Stations 6 and 7, the proportion of body surface burned varied from 0 to 50 percent. There was an inverse association between degree of burn and survival time of the exposed animals. There was no apparent effect on the course of wound healing in animals receiving less than 84 rep. In animals wounded or in animals burned and wounded, the clinical healing of the wounds and burns appeared to be little influenced by whole-body irradiation. However, the levels of radiation were too low for this phase of the experiment to be conclusive.

It appeared that combined injuries of the degree experienced in the 7-psi overpressure region of Shot Priscilla (Table 5.1) shortened the survival time by as much as 30 percent when compared to the swine exposed to radiation only from Shot Wilson. Under the conditions of Shot Priscilla, ionizing radiation was the decisive injurious agent in nearly all casualties that did not die prior to or soon after recovery. Within the precursor region, the primary cause of death was mechanical injury to the organism as a result of translation. The simulated battlefield environment, which was limited to selected items of equipment, did not contribute to casualty production.

The immediate effect upon the close-in animals was impressive. Within the precursor region, the animals suffered mass destruction, dismemberment, gross translation, and severe burns. At Stations 1 and 2, all animals, except the pig in the foxhole, had been blown out of the exposure pens, and the inclosure fence no longer existed. All animals had apparently been killed almost instantly, with the animals from Station 1 being blown beyond Station 2. At Station 3, the primary cause of death was again found to be mechanical injuries due to translation. Six of the 40 animals in the pen survived the blast. At Stations 4 and 5, the principal cause of death was radiation injuries, plus severe burns. At Station 4, of the 36 animals that were alive upon recovery, the first death occurred within H + 7 hours, and the last pig of the group died at H + 133 hours. All animals at Station 5 survived the initial period, with the first animals dying at H + 47 hours and the last of the group dying at H + 167 hours.

The results of the LD_{50-30} phase of the experiment were well-defined during Shot Wilson, even though the total radiation dosage received by the swine was greater than desired, and the neutrons were not as effectively shielded as in Franklin. Animals at 22 stations were exposed to doses ranging from 410 to 2,475 rep, with the gamma/neutron dose ratios varying from 1.05 at the highest total doses to 1.28 at the lowest total doses. Because of the nearly complete mortality of the animals, the relative biological effectiveness (RBE) of neutrons was not determined. The LD_{50-30} for pigs was determined to be approximately 486 rep (Figure 5.1), which compares favorably with information obtained from laboratory experiments but is considerably higher than the 230 r determined during Operation Greenhouse. In the Greenhouse experiment, some 90 percent or more of the total dosage was due to gamma rays, whereas in this experiment the gamma contribution was only slightly over 50 percent.

Two groups of 9 animals (each of which was exposed to supralethal dosages of radiation during Shot Wilson) and 34 animals (exposed during Shot Priscilla to lesser dosages of radiation) were given intravenous transfusions of a mixture of cells from spleen and bone marrow. The average survival time of the irradiated animals that received transfusions of spleen and marrow cells was no longer than that of other animals exposed to similar levels of radiation. All post mortems of the animals that received the transfusions gave no evidence of regeneration of the bone marrow.

The technique of pinhead leucocyte count appears to be acceptable for use on radiation victims. This method consists of taking a drop of blood that can be transferred from the head of an ordinary straight pin to a slide for staining, scanning, and comparing with photographs of known standards. The results of the pinhead count were checked with the count obtained by standard methods. The advantages of this method are its rapidity (1 or 2 minutes versus 15 to 20 minutes with standard methods) and the simplicity of the equipment required. By the pinhead technique for white blood count above 15,000, there was a tendency for the technician to underestimate the true count, whereas, in ranges below 10,000 there was a better correlation with the standard count. Peripheral white-blood count correlated well with the amount of radiation the animals received and gave an indication of the clinical course of the animals in that, when the peripheral white count fell below 2,500, death of the animals followed within 24 hours.

Five animals placed in machinegun-type field fortifications near ground zero for Shot Priscilla survived the blast effects, but four of the animals later succumbed to the radiation and thermal effects. The static pressures recorded at the stations are listed in Table 5.2. The radiation dosages recorded were unreliable. The animal that survived was recovered on D-day, but the four dead ones were not recovered until D+1 because of high residual radiation levels at the closer distances. Two animals placed in foxholes, 36 inches deep, at Stations 2 and 3 survived the blast and thermal effects, but death resulted from radiation exposure at 6 and 91 hours, respectively, after exposure.

For Shot Wilson, four animals were anesthetized and placed in the crew positions of a tank located 1,800 feet from ground zero. All of them were dead upon recovery at H+12. There was no evidence of struggling on the part of the animals, and, judging from the post-mortem changes seen, all animals had been dead for several hours. Because of the extremely high radiation dosage (Table 5.3), there is no possibility that a human tank crew could survive a similar experience.

5.2.2 Eye-Protective Shutter. This device was a high-speed electromechanical shutter, coupled with a flash detector and a power supply (Figure 5.2). The shutter consisted of a pair of movable glass plates, each inscribed with a series of opaque lines. The space between the lines was equal to the width of the lines. When the shutter was open, the lines of one plate were superimposed over the lines of the other, and, since the width of the lines was less than the pupillary width, vision was possible through the clear spaces between the lines, with no blind areas in the field of vision. The net effect was that of a neutral-density filter, with 20-percent light transmission. Each plate was held in position by a fine actuating wire, which restrained a spring.

When the flash detector sensed the presence of unusual illumination above a preset level, it produced a signal that discharged a capacitor in the power supply. The current, thus released, passed through the wires, causing thermal expansion to such an extent that each plate was moved one-half opacity width by its spring (one to the right, the other to the left). The opaque lines of one grid were then alined with the spaces of the other, effectively cutting off all light to the subject's eye. Another circuit held the shutter closed for a preset interval, after which time the wires cooled and contracted, pulling the plates back to their original positions and allowing the subject to see once again. The average shutter closure time was expected to be 0.5 msec after sensing of illumination by the detector. The detector could not only sense unusual brilliance but also discriminate intensities of a preset rate of increase. This precluded the actuating of the shutter if the subject would look toward a bright object, such as the sun.

Service personnel volunteers (mostly from the Tactical Air Command), with protective shutters, viewed the detonations from a C-47 aircraft and from a trailer exposure station. Control rabbits, both with and without protection, were subjected to the bomb light. All exposure stations were located at slant ranges where the total energy was expected to be between 0.04 and 0.1 cal/cm^2 so that, in case of shutter failure, the eye would not be exposed to more than a safe chorioretinal burn threshold. The critical threshold adopted for this project was 0.004 cal/cm^2 over the first 0.1 second.

To fully evaluate the effectiveness of the shutter, it was necessary to obtain thermal and photometric data as a function of time. Times of special interest were 0.5 and 100 msec, corresponding to the average shutter-closure time and to normal human-blink time, respectively. The Naval Radiological Defense Laboratory (NRDL), by use of calorimeters, determined the amount of thermal energy received at each station. Western photoelectric cells were used to measure incident light flux, and RCA 934 phototubes were used to determine short time illumination.

Immediately after exposure, the subject turned to a visual-testing device located slightly to the side of his position. Visual recovery was tested on either the stereocamptometer, or nyctometer, or a combination thereof. Time to recover useful vision was measured by ability to read aircraft instruments. The time of return to mesopic visual acuity was determined and recorded. Upon completion of visual recovery testing, all human subjects were returned to Nellis AFB for complete ophthalmological evaluation.

During Shots Wilson and Boltzmann, the shutters gave complete protection from chorioretinal burns and flashblindness (Table 5.4). Human volunteers observing the detonation through the operative shutters had no measurable recovery time and no scotoma, whereas unprotected rabbits exposed to the bomb flash received minimal chorioretinal burns.

During Shot Priscilla, only rabbits were exposed to the flash of the detonation. Animals behind inoperative shutters and viewing approximately 20 percent of the radiant energy received no burns. This proved that human volunteers can be exposed under these conditions without danger of permanent injury.

During Shots Hood and Diablo, volunteers behind operative shutters received full protection, whereas two subjects behind inoperative shutters suffered flashblindness with a definite recovery period. The time to recover useful vision was 10 and 12 seconds, respectively. Rabbits without protection and exposed to Shot Hood received minimal burns.

To investigate the possibility that the electromechanical shutters might be overdesigned, the closure time for the shutters was extended on Shot Diablo to approximately 1 msec. With the longer exposure time, the subject received full protection. It is concluded that a simple shutter, using the principle of operation reported but with a slower closure time and less closure density, will give adequate protection from low-altitude nuclear detonations up to a yield of 71 kt.

To evaluate the effect of personnel observing a detonation through a cloud, volunteers viewed the bomb light through a translucent plate of glass. The result of this test showed that an eye exposed in this manner is more acutely affected than the eye exposed to direct energy. Time to partial vision recovery is shorter when the light is viewed directly, but the possibility of permanent damage is greater. When the light source is viewed through a translucent medium, the possibility of permanent damage is small; but, due to the lack of image formation, the glare effect is all-encompassing, and the individual is completely flashblinded for a period of time.

5.2.3 Missile Studies. The study of missile parameters translated by a nuclear detonation (CETG Project 33.2) was made by Lovelace Foundation for Medical Research under the administrative control of CETO (formerly CETG). The specific objectives were: (1) to determine, for various dynamic pressures, the velocities attained by planted missiles, consisting of military debris at different ranges from a nuclear detonation; (2) to determine the mass and velocities of natural missiles; and (3) to analyze all data in a manner that would aid the assessment of secondary blast casualties. The DOD Test Group furnished part of the required funds and minor logistical support.

Experimental techniques, similar to those developed during Operation Teapot for the study of secondary missiles, were used during Operation Plumbbob. The technique involved the capture of missiles by an absorbing material, such as polystyrene or balsa wood. Velocity of the missile at impact was determined from the depth of penetration, missile mass, and impact area, utilizing calibration data obtained from laboratory experiments. Field experiments were conducted during Shots Priscilla, Smoky, and Galileo.

One hundred and fifty-five traps, having a total missile-collecting area of about 486 ft^2, were employed in open regions, shelters, and houses. In addition, approximately 234 ft^2 of missile-absorbing material cemented to walls was used to study missile behavior in a shelter and in open regions.

Secondary missiles were studied in open regions where the measured peak and over-pressures ranged from about 4 to 15 psi. The effects of hill-and-dale terrain upon missile production were investigated during Shot Smoky. Missiles used in the three shots were window glass mounted in frames, marked military debris, marked gravel, marked spheres, and native stone. Displacement distances were measured for stones (weighing up to 19 kg), which were placed at various ranges from ground zero.

For Shot Priscilla, 25 stones were placed at each of seven ranges varying from 2,030 to 6,120 feet from ground zero. Each group of 25 stones was divided into five subgroups, whose average masses ranged from 0.249 to 12,442 kg. At a given station, it was found that the smaller stones were displaced farther than the larger ones. The most significant result of this study was the marked difference in the displacements of stones placed at 2,730 feet or less and those placed at 3,930 feet or more from ground zero. The average displacements of the subgroups at the lesser ranges were from 614 to 1,262 feet, whereas the average displacements for those subgroups at the greater ranges were from 0.3 to 17.2 feet.

Analysis of the window-glass-missile data indicated that windows mounted in open regions do not produce missiles equivalent to those generated by the same kind of windows mounted in houses, even when similar slant ranges are involved. Glass missiles produced in open regions were larger than those generated in houses, but the velocities were smaller. For the windows mounted in houses, the glass-missile velocities appeared to have been enhanced by reflection of the shock wave from the adjoining walls. Further enhancement of missile velocities could have been caused by the funneling effect as the blast wave broke the window and spread into the house. The total effect on the missiles was as though the shock overpressures were more than twice as great as those actually incident upon the house.

An attempt was made to learn something of the displacement velocities for the human body by measuring the velocities attained by aerodynamically equivalent spheres. A similar type of study was made inside the Upshot-Knothole 3.7 shelter during Shot Priscilla. The entry way was left open; the maximum overpressure measured outside the shelter was 65.4 psi. The velocities of six $\frac{1}{2}$-inch-diameter and two $\frac{9}{16}$-inch-diameter steel balls were measured by use of suitable absorbing material cemented to the shelter wall opposite the door. The difference in sphere sizes was an attempt to account for varying weights and possible orientations of the human body. The impact velocities of the six smaller spheres ranged from 99 to 159 ft/sec after about 15 feet of travel, whereas the impact velocity for the two larger spheres was 53 ft/sec after about 10 feet of travel.

5.3 SUMMARY

5.3.1 Biomedical Project. The midlethal dose (LD_{50-30}) of nuclear radiation was approximately 486 rep, more than twice that previously observed at a nuclear test. The radiation syndrome noted and the median survival times acertained were similar to those observed for other mammalian species after comparable exposure doses during laboratory experiments.

The animals exhibited morbidity and mortality when exposed to the combined effects of a nuclear detonation. Combined injury of whole-body radiation plus wounds and/or burns resulted in a definitely shortened survival time over that of the animal exposed to comparable levels of radiation alone. The midlethal dose was approximately 100 to 125 rep lower for the animals exposed to all the effects than it was for the animals exposed to pure ionizing radiation.

On animals wounded or burned and wounded, the clinical healing of the wounds or burns appeared to be little influenced by irradiation, except at lethal levels. In those animals that received supralethal levels of radiation, the burns were dry and grossly healing at the time of death.

When a large biological specimen is exposed in the open to a nuclear detonation, virtually 100-percent mortality, either from dismemberment or severe translation, will occur within the precursor region. A foxhole within this region will protect against the precursor effect and give line of sight thermal shielding but will not necessarily furnish protection against ionizing radiation. Blast-translated battlefield debris is not an important cause of casualties except within the precursor region where it is an incidental finding and is thus of no clinical significance.

Medical officers in the field who observed the animals in the early postdetonation period gave a rapid and accurate portrayal of the dominant injury, although definition of the extent or degree of thermal injuries was difficult. However, the combat physician intuitively recognizes the injury that requires immediate therapy—in this case, the mechanical wounds. The ionizing radiation syndrome was not recognized in the early postdetonation period, because there were no signs or symptoms. Sorting and treatment of casualties can be done only on a symptomatic basis.

The pinhead count method of performing total leukocyte counts is a faster and more accurate method than the standard chamber count for qualitatively analyzing the exposure to clinically significant doses of ionizing radiation.

5.3.2 Eye-protection Shutter. The electromechanical shutter tested during this operation provided protection from flashblindness and chorioretinal burns of the exposed human and animal eyes at distances as close as 15,000 yards from a 10-kt detonation. As a result of these tests as well as from past field studies of chorioretinal burns, a closure time of 0.5 msec (from onset of the flash) will furnish adequate protection against the deleterious effects of visible and thermal radiant energy incident from low-altitude nuclear detonations of yields ranging from 10 to 71 kt. It is concluded that these shutters are sufficiently developed for incorporation into a goggle for service testing.

5.3.3 Missile Studies. It was found that the velocities attained by stones that are displaced by the blast wave from a nuclear detonation are dependent on the size of the stones, with the smaller stones attaining higher velocities and achieving greater displacements. On the other hand, fragments from windowpanes subjected to the same overpressure on the glass surface appear to achieve the same velocity regardless of the size of the fragments. However, higher overpressures will, in general, produce smaller windowpane fragments. Since it is generally accepted that windowpanes are mounted in houses, it follows that these panes, when facing ground zero, will break as if they were subjected to more than twice the overpressure experienced in an adjacent open area.

Velocities achieved by man-equivalent missiles indicate that severe displacements could occur to humans when exposed in the open to high overpressures. This is substantiated by translational injuries to swine when exposed in similar regions.

TABLE 5.3 MIDLINE GAMMA DOSE TO SWINE IN TANK, SHOT WILSON

Ground range: 1,800 feet.

Position	Gamma Dose
	r
Tank commander	23,000
Gunner	18,100
Assistant gunner	18,500
Driver	17,750

TABLE 5.4 RESULTS OF ELECTROMECHANICAL SHUTTER TESTS

Blank spaces indicate lack of conclusive data.

Shot	Yield	Distance from Ground Zero	Radiant Exposure	Peak Illumination	Unprotected Rabbits	Rabbits Behind Inoperative Shutters	Human Volunteers Behind Operative Shutters
	kt	yd	cal/cm²	lumen/ft²	controls		
Boltzmann	11.5						
Ground station		17,600	0.055	42,500	Minimal burns	No burns	No recovery time, full protection
Air station		21,200	0.050	–	Minimal burns	No burns	No recovery time, full protection
Wilson	10.3						
Ground station		15,136	0.105	120,000	Minimal burns	–	No recovery time, full protection
Air station		19,360	0.083	–	Minimal burns	–	No recovery time, full protection
Priscilla*	36.6						
Ground station		20,649	0.180	96,000	No burns†	No burns	—
Air station		30,400	0.093	83,600	Burns	No burns	—
Hood	71						
Air station		32,426	0.096	63,000	Minimal burns	–	No recovery time, full protection
Diablo	17.0						
Ground station		18,304	0.035	13,200	No burns	–	No recovery time, full protection

* Human subjects were not exposed to Shot Priscilla. † Lack of burns is explained by partial obscuration of the fireball.

TABLE 5.1 PROJECT 4.1, SHOT PRISCILLA

Station	Distance from GZ	Number of Animals	Glass Missiles	Battlefield Debris	Maximum Peak Overpressure	Peak Dynamic Overpressure	Thermal Exposure	Gamma (Air)	Neutron (Air)	Animal Dead When Recovered	Mean Survival Time *
	ft				psi	psi	cal/cm²	rep	rep		hours
1	2,630	20	No	No	10.0	26.3	85	12,100	8,700	20	0
2	2,730	20	No	No	9.9	22.0	82	10,200	7,200	19	6 †
3	3,000	40	No	Yes	9.8	13.0	75	6,500	4,290	34	52
4	3,930	40	No	Yes	9.2	1.9	53	1,490	770	4	86
5	4,150	40	No	Yes	8.5	1.4	49	1,070	525	0	90
6	4,430	145	Yes	No	7.3	1.1	44	711	323	11	100-10 ‡
7	4,770	145	Yes	No	6.1	0.76	39	435	180	2	97-21
8	5,320	110	Yes	No	4.9	0.48	32	197	71	1	35-21
9	6,120	70	Yes	No	3.7	0.26	24	65	19.4	0	§
10	7,380	40	No	No	2.4	0.1	15	12.2	4.2	0	¶
11	9,490	40	No	No	1.4	0.1	6.9	1.1	0.2	0	¶

* Mean survival time of animals excluding those dead when recovered. † One animal in foxhole. ‡ Mortality 100 percent in 10 days.
§ Data inconclusive. ¶ Living at the end of 30 days.

TABLE 5.2 MACHINEGUN NESTS, SHOT PRISCILLA

Station	Ground Range	Earth Shielding *	Outside Overpressure	Entrance Overpressure	Emplacement Overpressure	Recovery Time	Survival Time	Cause of Death
	ft	ft	psi	psi	psi	hours	hours	
A1	1,435	9.55	52	25.2	17.8	H + 32½	97	Radiation, burns
A2	1,720	11.2	25.4	†	13.9	H + 32⅓	109	Radiation, pneumonitis
A3	1,720	11.2	25.4	14.17	19.2	H + 28	173	Radiation, burns
A4	2,280	14.2	11.2	14 67	12.9	H + 28¼	235	Radiation, burns, pneumonitis
A5	2,280	14.4	11.2	14.4	15.2	H + 4		Permanent survivor

* Line of sight from detonation to subject. † Not determined.

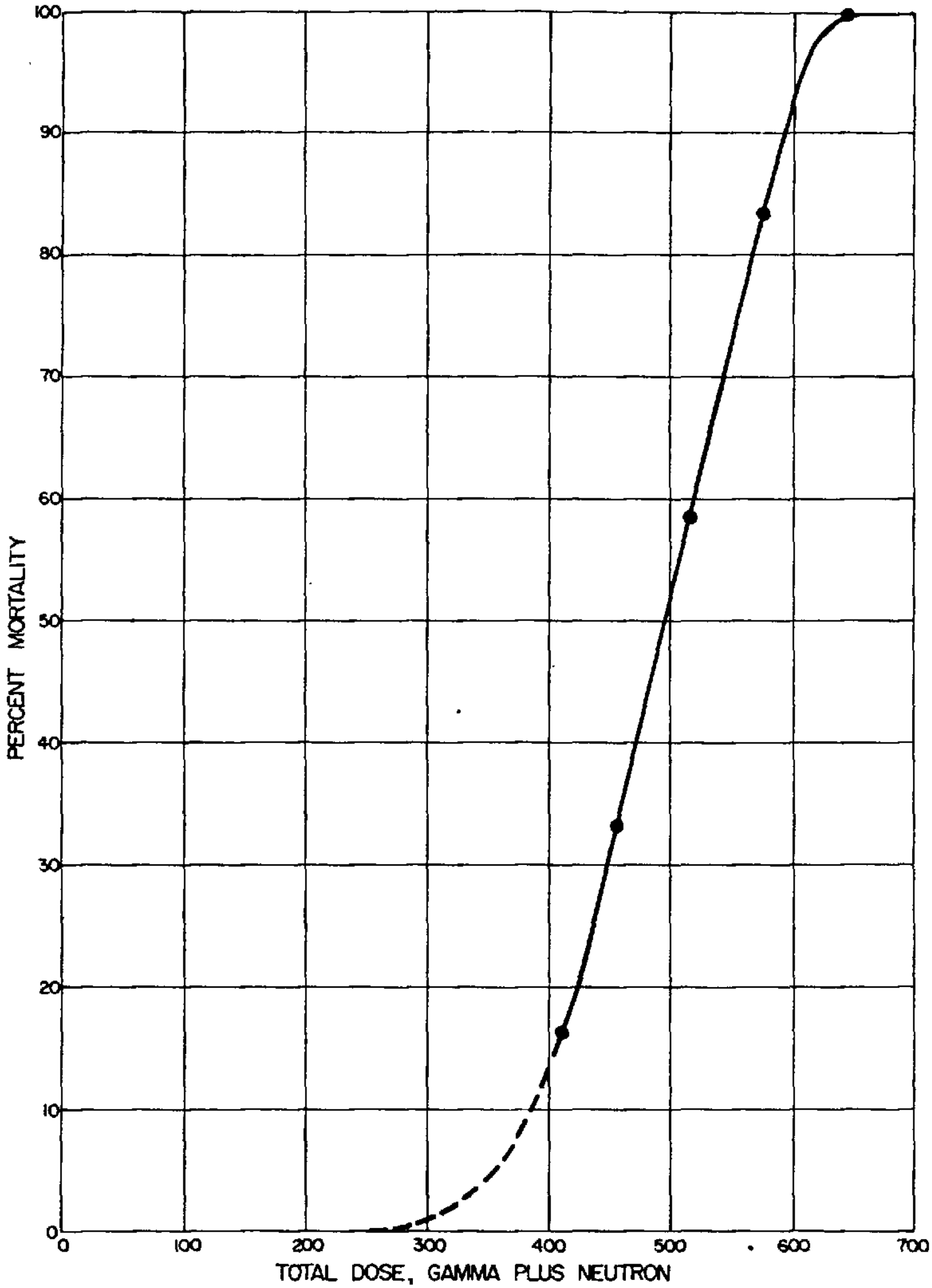


Figure 5.1 Thirty-day mortality for swine.

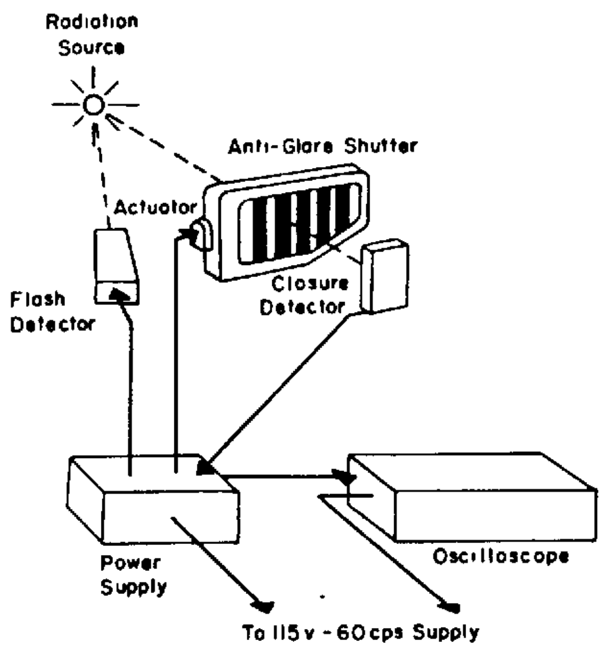


Figure 5.2 Antiglare-shutter system.

Chapter 8

THERMAL RADIATION MEASUREMENTS AND EFFECTS

Program 8 consisted of three projects: (1) thermal protection of the individual soldier, conducted by the Quartermaster Research and Development Center of the Army; (2) effects of thermal radiation on a standard-reference material and evaluation of laboratory methods for determining the protection afforded by uniform systems, conducted by the Naval Material Laboratory (NML); and (3) testing and evaluating certain types of instrumentation, namely, streak spectrograph, Naval Radiological Defense Laboratory (NRDL); weapon effects on materials and instrumentation systems inside the fireball, Wright Air Development Center (WADC); and thermal measuring instrument components, Air Force Cambridge Research Center (AFCRC).

8.1 THERMAL PROTECTION OF THE INDIVIDUAL SOLDIER

The long-range objective of this project was to make studies leading to thermal protection for the individual soldier and his clothing in the range of 10 to 30 cal/cm^2. Three experimental hot-weather uniforms, a flashburn protective cream, and several types of shielding materials were tested during Shot Priscilla. Young pigs clothed in the uniforms and protected by the various protective devices in various arrays were used as animate receivers. The pigs were of the Chester White breed.

One of the hot-weather uniforms consisted of an outer layer of cotton poplin (non-fire-retarded), 5 oz/yd^2, Shade 116, and an inner layer of tubular knit cotton, 3.2 oz/yd^2 (T-shirt). The materials were new fabrics, unwashed. This uniform ensemble is presently recommended by Continental Army Command (CONARC) for standardization. It has been previously tested during Operation Upshot-Knothole and was, therefore, used during Operation Plumbbob as a control. It is identified in the text as HWC. A second uniform consisted of an outer layer of fire-retardant-treated cotton poplin, 5 oz/yd^2, an intermediate layer of tubular knit 50/50 cotton-wool, 4.5 oz/yd^2, and an inner layer of tubular knit cotton, 3.2 oz/yd^2. The materials were new fabrics, unwashed. This uniform ensemble is identified in the text as HWU. The third uniform consisted of an outer layer of fire-retardant-treated cotton poplin, 5 oz/yd^2, an intermediate spacer layer of heat-set polyethylene cloth, and an inner layer of tubular knit cotton, 3.2 oz/yd^2. The intermediate spacer layer provided approximately $^1/_4$ inch of airspace between the inner and outer layers. The materials were new fabrics, unwashed. This uniform ensemble is identified in the text as HWS.

Also tested during Operation Plumbbob were an experimental flashburn cream, water-in-oil No. 305X, $^1/_{16}$ inch thick, identified in the text as FC; a flash-off reflector-insulator shielding material consisting of an outer flash-off layer of vicara, an intermediate reflector layer of aluminized scrim, and $^1/_8$-inch inner insulating layer of ensolite, identified in tables as FRI; a shielding material of cotton poplin, Shade 116, 5 oz/yd^2, fire-retardant treated, identified in the text as SF; and a shielding material of cotton sateen, OG 107, 8.5 oz/yd^2, non-fire-retardant treated. The latter is the base fabric used in the gas cape and is identified in the text as SS.

During this field test, the outer layers of all uniforms unprotected by shields were destroyed at all energy levels investigated. In addition, in most cases the inner layers were also destroyed or damaged to the point of uselessness. At the same time, the two new experimental uniforms HWU and HWS did provide a fair amount of protection to the animals, primarily because they did not flame. The burns received directly from radiant energy or from glow areas in the fabric were less severe and much more extensive than those received under the control uniform HWC, which was not fire retarded and which flamed. It may be concluded, that, although a certain amount of protection was achieved in these experimental uniforms, not one of them will stand up and be reusable under the energy levels of interest to CONARC.

It should also be noted that the HWU and HWS uniforms that did not flame were new, unlaundered materials that had been chemically treated for fire retardance. The effects of wear and laundering on the surface absorptivity and ignition probabilities were not taken into consideration and, therefore, this test was not truly representative of field conditions. Under the test conditions, the uniforms had the maximum chance of survival. In addition, the effects of wear and laundering on the chemical fire retardant are unknown or unaccounted for in the test, so any degradation in fire retardance due to those causes was not represented. Although the value of fire retardance or flameproofing was startlingly demonstrated in this test, it seems unreasonable to expect that chemical fire retardance can be maintained in the field to a suitable level. It appears that future investigation should be directed toward providing fibers having this feature as an inherent characteristic.

Finally, a shielding material of neoprene-coated Fortisan poncho material, identified in the text as SP, and a new type of passive calorimeter, developed at the University of Rochester, were tested.

Flaming of materials was the most startling effect noted during the Plumbbob tests. The extent and severity of burns on the animals from this cause far exceeded those from radiant burns. Most of these burns were produced in the unshielded non-fire-retarded hot-weather control uniforms (HWC) and ranged from 2+ to 5+ over large areas at all energy levels from 10 cal/cm^2 up. (Drythema of the skin signifies a 1+ burn; carbonization of the skin signifies a 5+ burn. There are corresponding intermediate numerical designations. It has been reported that 1+ and 2+ burns on pigs correspond to first- and second-degree burns in humans whereas 3+, 4+, and 5+ relate to third-degree burns of varying severity.)

In contrast to the above, the burns on the animals clothed in the unshielded fire-retarded HWU and HSW uniforms were considerably less extensive and severe, even though the fire-retarded outer layer was completely destroyed, ranging from 1+ to 3+ over scattered small areas with an occasional small area as much as 4+. The evidence presented makes fairly obvious the value of flameproofing or fire-retardation in mitigating both the extent and severity of burns to be expected.

The effects of energy delivery rate, shock arrival, and shock strength and their variation with yield were studied. Although the results obtained on this test, both favorable and unfavorable, are conclusive in some respects, they may well be misleading and only appear conclusive in other respects. These results were obtained under a particular set of conditions, and these conditions may vary. One of the more important of these variables is the yield of the weapon.

With yield, certain other related and dependent functions of importance to the subject also vary, some in such a manner as to mitigate the effects reported here, others in such a manner as to aggravate them.

The first function to be considered is energy-delivery rate. For a given exposure (total energy delivered to a unit area), the peak irradiance (rate at which energy is delivered to a unit area) decreases with increasing yield. Another way of saying this is that, as the yield increases, it takes more time to deliver the same amount of energy to a unit area. This increased time permits conduction and cooling phenomena to be more effective; hence, less damage is expected from the same total exposure. This is a mitigating function whose effect is to decrease damage with increasing yield.

The second function to be considered is shock-arrival time, since arrival of the shock may put out burning already started or may remove burning materials; for any given exposure, the time of shock arrival increases with increasing yield, permitting more burning time. This is an aggravating function that increases with increasing yield.

The third function to be considered involves both the magnitude and the velocity of the shock, which determine whether or not the shock wave is capable of putting out burning. The range to which a given shock will extend increases more slowly with yield than the range to which a corresponding thermal exposure extends. Therefore, with higher yields it is possible to ignite materials at ranges that will never be reached by a shock of sufficient magnitude and velocity to extinguish them. This function is, therefore, an aggravating one whose effect is to increase damage with increasing yield.

Although it is not practicable to conduct tests of materials under all conditions, much can be learned concerning the effects of these functions from laboratory studies and from theoretical and mathematical analyses.

Tables 8.1 through 8.3 give the results of the experiments on thermal protection for the individual soldier.

8.2 EVALUATION OF LABORATORY METHODS FOR STUDYING EFFECTS OF THERMAL RADIATION ON BIOLOGICAL SYSTEMS

This experiment was conducted by NML under Project 8.2. A plastic skin simulant developed at NML that has the thermal properties of human skin, closely resembles human skin in optical characteristics, and utilizes a temperature criterion as a measure of burn levels was tested during Shots Lassen, Wilson, Priscilla, and Hood. The primary effort was made during Shot Priscilla, where pigs were exposed concurrently under identical conditions. The objectives were to compare the temperature maxima and burn predictions obtained therefrom in the field with those obtained in the laboratory under simulated similar conditions, to validate the laboratory methods. At the same time, a comparison of burn predictions from the simulant data taken in the field with actual burns on animate skin obtained in the field under identical conditions provided a correlation between the simulant and animate skin under these conditions. A considerable amount of laboratory work on this correlation had preceded the field effort.

Six basically different uniform-simulant configurations were used: (1) plain skin simulant; (2) blackened skin simulant; (3) the Army's experimental hot-weather uniform consisting of a 5-oz/yd^2, Shade 116, cotton poplin outer layer with a 3.2-oz/yd^2 tubular knit cotton (T-shirt) material inner layer (see WT-1440) covering the simulant in close contact; (4) same assembly as Item 3, but with a 5-mm space between the uniform materials and the simulant; (5) a dark-gray, 9-oz/yd^2, cotton-sateen outler layer with a 4-oz/yd^2 white sheeting both in firm contact with the NML simulant; and (6) same assembly as Item 5, but with a 5-mm space between the material and the simulant.

Apertures on the above arrays were varied, to analyze the possible effect of varying exposure areas on the results obtained. Apertures 0.9, 1.7, 3.5, and 7.5 cm in diameter were used.

Some samples were placed under neutral screens of known attenuation at each station, to obtain the maximum exposure variation with the minimum number of stations.

The results are shown in Tables 8.4 through 8.9 for Shots Wilson, Priscilla, and Hood. Because of the extremely low yield of Shot Lassen, no data was obtained.

During Shot Wilson, the temperature of the bare simulant was 17 percent less than predicted, the blackened simulant 31 percent less. The clothed-simulant temperatures were high and characteristic of flaming or glowing cloth, which was as expected at the radiant exposure encountered. The temperatures recorded in Table 8.4 for the bare simulants are in close agreement with those predicted by laboratory methods, as are the high temperatures under the clothed simulant where flaming occurred.

At the 7,500-foot station, Shot Priscilla (Table 8.5), the temperatures for the bare skin simulant are close to those predicted from laboratory exposures. The blackened simulant temperature was also close to predicted value. High temperatures predicted for fabrics in contact for both large and small apertures occurred. The higher temperatures predicted for simulants with 3.5- and 7.5-cm apertures with spaced sateen did not occur, probably because of the removal of the flaming cloth by the blast arrival.

At the 12,150-foot station, Shot Priscilla (Table 8.6), one oscillograph failed to run, causing the loss of data on the bare skin simulant and on the simulant with spaced fabric. Predictions based on laboratory measurements indicated a temperature rise of 42° in the bare simulant, resulting in a more severe burn than was actually observed on the animal skin. For the simulant covered with sheeting, however, laboratory data indicated that a low simulant temperature was to be expected and, thus, predicted the no-burn observation. The temperatures for the 3.5-cm apertures were, in the two cases recorded, lower than those for the 0.9- and 1.7-cm apertures. The higher temperatures under the smaller apertures predicted at least as severe a burn as that predicted by the larger exposure area. Unfortunately, the data for the largest (7.5-cm) aperture was lost as a result of recorder malfunction.

The skin-simulant temperatures during Priscilla adequately predicted the skin burns in three of the four situations where a comparison was possible and the no-burn observation under the spaced assembly at the 12,150-foot station (Table 8.7). It failed to predict the no-burn observation for the one contact case.

During Shot Hood the skin simulant temperatures were much higher than predicted by laboratory methods for 18.3 cal/cm^2. The differences between laboratory prediction and field test would be small, however, if the exposure were actually 15 cal/cm^2.

As in the Priscilla exposures, the high temperatures experienced in the laboratory for the 3.5- and 7.5-cm apertures did not occur in the field during Hood; again, removal of flaming materials by the blast is suspected (Table 8.8). The difference between laboratory-predicted and field-recorded temperatures has no significance; lack of protection would be indicated by ignition and not by temperature rise. Laboratory methods predicted the degree of lack of protection in all the situations exposed without screens during Shot Hood.

The laboratory and field temperatures for the screened exposures during Shot Hood are listed in Table 8.9.

The correspondence of skin-simulant temperatures for the six configurations show that laboratory methods employing the carbon-arc thermal radiation source with the shutter for simulating nuclear weapons pulses are adequate. Since there were no systematic differences larger than 10 percent between temperatures of the spectrally different bare and blackened simulants and the spectral-selective poplin and neutral-gray sateen, the spectrum of the laboratory carbon-arc thermal source may be considered adequate for this range of spectral selectivity. Except for the several cases of laboratory-field differences attributed to blast, the temperatures predicted behind spaced fabrics indicate that the laboratory sources are adequate in exposure area. The experiment design as to radiant exposure selection was successful in that exposures were obtained both below as well as above the important burn thresholds. The skin-simulant temperatures adequately predicted the burns observed on the animals where comparison was possible.

8.3 THERMAL EFFECTS ON A STANDARD REFERENCE MATERIAL

The objective was to determine the adequacy of the laboratory methods employed in studying the effects of intense thermal radiation on materials. In particular, the influence of source parameters (such as irradiation area, time variation of irradiance, and spectrum were studied.

Participation for this experiment was during Shot Priscilla only. The materials were exposed at the two major project stations at 7,500 and 12,150 feet and at four minor stations at 6,450, 8,400, 9,000, and 10,000 feet. All distances are horizontal distances.

Alpha-cellulose paper was selected for this study, since it represents an idealized kindling fuel over whose material parameters optimum control can be exercised. In addition, two fabrics, poplin, Shade 116, 5 oz/yd^2, and sateen, gray, 9 oz/yd^2, were also exposed. The alpha-cellulose paper was exposed behind four different aperture sizes. For both the fabrics and the paper, additional apertures were used to expose an edge of the material, to verify laboratory studies on the edge effects. Apertures used were 0.9, 1.7, 3.5, and 7.5 cm in diameter. Edge exposures used a 3.5-cm aperture.

Table 8.10 presents comparative laboratory results. Tables 8.11 through 8.16 present the results obtained during Shot Priscilla. It was difficult to determine thermal effects, because the blast removed most of the material from the apertures. However, by examination of the shreds of material remaining and similar materials that had been exposed in the laboratory, it was possible to determine the presence of charring and the probability ignition in each aperture.

The data from Shot Priscilla indicates that laboratory methods for studying ignition of cellulosic materials are adequate as to radiant exposure, pulse shape, and geometry. Because of blast effects, any definite differences in thermal effects due to aperture size were obscured.

No apparent contradictions between laboratory effects and field effects exist except at the 6,450-foot station, where the 30.3-mil-thick alpha-cellulose paper was presumed to have not ignited from examination of the residue. Since the laboratory exposure for ignition is 19 cal/cm^2 and the exposure at the station was 21 cal/cm^2, there is the possibility that ignition had started and had not gone to completion when the blast arrived.

The data yielded by examination of the materials exposed to Shot Priscilla indicated that the laboratory methods employed by NML for studying ignition of cellulose materials would yield qualitative data that was within 25 percent of expected field data.

8.4 TEST OF THE THERMAL-RADIANT-EXPOSURE METER (TREM)

This experiment was carried out by NML under Project 8.2 as an incidental part of their instrumentation work in connection with their main effort and that of Projects 4.1 and 8.1. The meter tested was a new type passive calorimeter developed at NML. It consisted of a copper plate of uniform thickness, blackened on the front face for exposure to radian energy Against the backface were placed, in point contact, a series of pellets with precise melting temperatures. The pellets are obtainable over a wide range of temperature intervals of approximately 7° C.

The results obtained are reported in Tables 8.17 through 8.21 and Figure 8.1.

Results show that the data obtained by the TREM was in general agreement with that obtained by other instruments as to the exposure level. In addition, the precision (a measure of the scattering of the data) obtained by the TREM appears to be better than that obtained by the metal-foil instruments.

All thermal-measuring instruments are pulse sensitive in the sense that their results are functions of opposing variables in the form of energy delivery and cooling rates. In the case of an instrument whose result is not a time-based record to which corrections for these functions may be applied based on the record, it is necessary either to calibrate the instrument throughout the entire range of thermal pulses for which the instrument is to be used or to calibrate it for each specific intended use. The TREM is such an instrument.

8.5 BASIC THERMAL RADIATION MEASUREMENTS

Under Project 8.2, NML made basic thermal measurements during Shots Lassen, Wilson, Priscilla, and Hood. These were in support of the main efforts in Projects 4.1, 8.1, and 8.2. At the request of Headquarters, Armed Forces Special Weapons Project (now Defense Atomic Support Agency, DASA), measurements were attempted during Shot Lassen, and four additional stations, extending out to 50,000 feet, were instrumented for Shot Priscilla, to learn something about atmospheric transmission.

Several types of instruments were employed in this work: (1) the NRDL Mark IV disk-type recording calorimeter, which records thermal energy received as a function of time, used as a reference standard; (2) a copper-disk-type recording calorimeter of similar nature to the NRDL instrument; (3) a metal-foil-type passive calorimeter used by NML on previous operations, recording only the maximum exposure; (4) the TREM, described above; and (5) the NRDL Mark IV foil-type recording radiometer, used to measure irradiance as a function of time.

For Shot Priscilla, one of the recording calorimeters at each of the two major stations (7,500 and 12,150 feet) was mounted 3.5 feet aboveground to serve as a check on the self-contained calorimeters used for Project 8.1 at this height; the other recording instruments were placed at a height of 7 feet. Metal-foil calorimeters were mounted at each of the stations of Projects 4.1, 8.1, and 8.2. At stations of Projects 4.1 and 8.1, the instruments were mounted at the level of the exposed animals; at the Project 8.2 stations they were placed at the height (7 feet) of the specimens and recording calorimeters. Two instruments were placed at each location, one behind a neutral attenuating screen. The TREM instruments were placed at each location where other calorimeters were employed; in addition, these instruments were used at 19,000, 27,000, 37,000, and 50,000 feet.

The station for Shot Lassen was at 3,930 feet. The yield of Shot Lassen was so low that no results were recorded on any of the instruments. The sensitivities of the instruments were such that the radiant exposure at the station (3,960-foot slant distance) was less than 0.008 cal/cm^2.

The radiant exposure measured at the Project 4.1 station at 2,590 feet during Shot Wilson was not appreciably greater than that at the 2,720-foot station. The area was not stabilized, and it is surmised that this may have been due to popcorning of the sand or to blast arrival effects, producing clouds of dust and obscuring the instruments for part of the thermal pulse.

The results from Shots Wilson and Priscilla are reported in Tables 8.17 through 8.21.

For Shot Priscilla, the radiant exposure readings of the foil meters under the screens are evidently low. The transmissions for the various screens and screen combinations were determined by the use of sunlight as a source and are considered to be correct to within 5 percent. The discrepancy is probably attributable to a deposition of dust in the fine screens. At the three close-in stations of Project 4.1, the quartz windows of the TREM instruments were gone, and the instruments were filled with dirt. The front-window retaining plate showed evidence of surface melt and missile damage. The indicating pellets were intact and are believed to correctly indicate the energy actually received at the stations. The recorded energies are lower than those predicted by TM 23-200 (Reference 6); however, this is probably due to the effect of clouds of dust raised at blast arrival.

One station was instrumented for Shot Hood. A rough check was made on the amount of energy scattered or reflected into the instruments on this shot. A tube 5.9 cm in diameter and 33 cm long was placed in front of one of the copper-disk calorimeters, giving a half-angle field of view of 5°. The portion of energy excluded was 15 percent. Table 8.22 summarizes the data.

8.6 TEST OF A STREAK SPECTROGRAPH

This test was conducted as Project 8.3a by the NRDL. Two streak spectrographs were to be tested—one a type used by the Naval Research Laboratory (NRL) on previous operations, the second a prototype consisting of a Hilger small quartz spectrograph with a film-drive system being developed at NRDL. The tests were conducted to evaluate the instruments, to learn something of their sensitivity limits, and to provide experience to the personnel.

The tests were considered successful in all respects, though some difficulty was encountered with the film-drive mechanism on the NRL instruments. Obtaining data was not an objective. The records are on file for possible future use. Good spectra were obtained on all shots except Lassen. Qualitative data analysis appeared to indicate that on the highly shielded shots, Diablo and Kepler, no Teller light was present, and the first pulse was mostly continuum with little or no apparent structure.

8.7 WEAPON EFFECTS ON MATERIALS AND INSTRUMENTATION SYSTEMS INSIDE THE FIREBALL

Project 8.3b exposed specimens within or near the fireballs of Shots Priscilla and Smoky to proof-test experimental instrumentation systems and to achieve more detailed information concerning the thermo-mechanical effects of a nuclear detonation with an ultimate objective of determining the structural vulnerability of ICBM's. This work is related to previous participations by Project 5.4 of Operation Teapot and by Project 5.9 of Operation Redwing.

Of the 25 specimens exposed, 4 contained time-history instrumentation consisting of an 8-channel magnetic tape recorder with strain gage and thermocouple transducers. Mechanical instrumentation (MI) included peak-pressure gages in four specimens, velocity-distance impact gages in five specimens, and thermal intensity gages in eight specimens. Four specimens were specifically designed as carriers for inserts of various materials including ceramics, metals, and polymers. Nine spheres of various materials were exposed to obtain additional ablation data. In addition, one solid graphite sphere was exposed to determine the effects of neutron bombardment. For Shot Smoky, 24 of the specimens were exposed at ranges from 150 to 1,380 feet from the burst point. The majority of the specimens were suspended from cables extending from the shot tower to deadmen.

Of the 25 specimens exposed, 24 were recovered. The high radiation level after Shot Smoky delayed the major recovery effort for approximately 5 months. The tape transport system from two of the five tape recorders operated satisfactorily, for the recording tape supply became exhausted. One recorder operated successfully through time zero but was subsequently damaged from lateral acceleration, and the tape was severely damaged from excessive heat. One recorder operated momentarily, moving the tape approximately

$\frac{3}{8}$ inch. The exact cause of failure has not been determined. The recorder exposed during Shot Priscilla operated a short time before the tape wrapped around the pinch roll, subsequently jamming the recorder. Of the three tapes that yielded signals during the time of interest, one tape provided four channels of information that could reasonably be construed as transducer outputs. Consideration of several factors involved in the data reduction process, however, casts some doubt on the amplitude validity of the data.

Transistor oscillators of the type employed in the instrumented specimens are not capable of operating satisfactorily at a slant range of 350 feet or closer for a yield similar to that of Shot Smoky. Strain-sensitive transducers employing bonded wire strain gages are capable of being exposed inside the fireball of a nuclear detonation without an appreciable change in the calibration factor at a slant range of 350 feet or greater with exposure conditions and yield similar to that of Shot Smoky. It is believed that the state of the art of recording fireball phenomena was advanced as a result of this test; however, it is believed the art of recording is not sufficiently advanced at this time to obtain usable data at a slant range of 160 feet or closer for a yield similar to that of Shot Smoky using the instrumentation techniques employed during Shot Smoky.

Three specimens instrumented with velocity-distance impact gages yielded apparently reliable velocity versus distance data and, subsequently, specimen acceleration versus time data.

During Shot Smoky, the Haveg Rocketon and plastic materials provided adequate thermal protection for the tape recorders located in the electrically instrumented (EI) cylinder at a slant range of 160 feet. The plastic shell and materials provided adequate thermal protection for the tape recorder located in the electrically instrumented steel sphere, at a slant range of 350 feet. The reduction in radius of the spherical plastic shell surrounding the electrically instrumented steel sphere, was approximately $2\frac{1}{2}$ times the reduction in radius of a solid steel sphere of comparable size and weight located at the same range. Both spheres were exposed at a slant range of 350 feet.

Figures 8.2 through 8.13 show the specimen array and examples of specimen configurations before and after shot. Table 8.23 outlines information concerning the individual specimens.

TABLE 8 1 DAMAGE TO SKIN AND ENSEMBLE OF PIGS CLOTHED IN THE HOT-WEATHER CONTROL UNIFORM (NON-FIRE-RETARDANT TREATED POPLIN AND TEE SHIRT MATERIAL) AFTER EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Station Location and Ensemble	Pig No.	Radiant Exposure	Burn Damage to Skin Indicated at Examination 24 Hours after Exposure	Damage to Uniform Ensemble
		cal/cm²		
64-HWC-1	91	21	Background of 2+ s with areas of 3+, large 5+ from flaming.	Cotton poplin destroyed, tee shirt charred with glow spots.
64-HWC-2	63	21	4+ and 5+, much of skin tanned, animal moribund Severe burns on right side.	Both layers of entire ensemble almost totally destroyed, evidence of flame and glow
64-HWC-3	156	21	4+ and 5+ with areas of 2+ and 3+ charring due to flame.	Cotton poplin destroyed. Tee shirt charred with glow spots
64-HWC-4	98	21	4+ effect at neck drawstring. 2+ with 4+ and 3+ areas	Cotton poplin destroyed, tee shirt charred with large portions showing evidence of glow
75-HWC-1	40	14.5	Numerous 5+ and 4+ areas, general 2+ mild shading to 3+ at edges.	Both layers of ensemble destroyed, evidently by flames.
75-HWC-2	114	14.5	Died during night, apparently due to severe burns	Uniform almost totally destroyed, remaining portions charred
75-HWC-3	184	14 5	5+ all over.	Uniform almost totally destroyed
75-HWC-4	45	14 5	5+ areas, scattered 4+ with some 3+.	Cotton poplin destroyed, large sections of tee shirt destroyed with glow spots on remainder
90-HWC-1	78	10	2+ shading to 3+ bad flame burns.	Cotton poplin destroyed, tee shirt charred.
90-HWC-2	168	10	Bad flame burns.	Cotton poplin destroyed, tee shirt charred.
90-HWC-3	208	10	Severe flame burns 4+ to 5+	Cotton poplin destroyed, tee shirt charred.
90-HWC-4	113	10	Bad flame burns, 5+.	Cotton poplin destroyed, tee shirt charred with small area of destruction.

TABLE 8.2 DAMAGE TO SKIN AND ENSEMBLE OF PIGS CLOTHED IN THE EXPERIMENTAL HOT-WEATHER UNIFORM ENSEMBLE (FIRE-RETARDANT TREATED POPLIN OUTER LAYER, 50-50 WOOL-COTTON INTERMEDIATE LAYER AND TEE SHIRT INNER LAYER) AFTER EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Station Location and Ensemble	Pig No.	Radiant Exposure	Burn Damage to Skin Indicated at Examination 24 Hours after Exposure	Damage to Uniform Ensemble
		cal/cm^2		
64-HWU-1	117	21	No burn.	Cotton poplin destroyed, 50-50 charred but intact, tee shirt scorched.
64-HWU-2	222	21	No burn over most of area, 2+ burn on belly	Cotton poplin destroyed, 50-50 partially destroyed, tee shirt charred in spots, otherwise scorched.
64-HWU-3	127	21	No burn.	Cotton poplin destroyed, 50-50 charred but intact, tee shirt scorched
64-HWU-4	62	21	Scattered 2+ areas on 1+ background.	Cotton poplin destroyed, 50-50 charred but intact, tee shirt scorched.
75-HWU-1	209	14.5	Areas of 3+ on 2+ background on shoulder, 2+ on flank.	Cotton poplin destroyed, 50-50 charred but intact, tee shirt scorched.
75-HWU-2	93	14.5	1+ to 2+ on shoulder, band of 4+ with 3+ on hip.	Cotton poplin destroyed, 50-50 charred but intact, tee shirt scorched.
75-HWU-3	140	14.5	Band of 3+.	Cotton poplin destroyed, 50-50 charred, tee shirt scorched.
75-HWU-4	159	14.5	Scattered 2+ with occasional 1+ areas.	Cotton poplin destroyed, 50-50 charred, tee shirt scorched.
90-HWU-1	130	10	Small char area on shoulder, 2+ areas on rear leg and side.	Cotton poplin destroyed, 50-50 charred, tee shirt stained.
90-HWU-2	35	10	Areas of 2+.	Cotton poplin destroyed, 50-50 charred, tee shirt stained.
90-HWU-3	54	10	No burn.	Cotton poplin 90 percent destroyed, 50-50 charred, tee shirt stained.
90-HWU-4	61	10	Two small areas of 2+ and one of 3+ near belly.	Cotton poplin destroyed, 50-50 charred, tee shirt stained.

TABLE 8.3 DAMAGE TO SKIN AND ENSEMBLE OF PIGS CLOTHED IN EXPERIMENTAL HOT-WEATHER UNIFORM ENSEMBLE (FIRE-RETARDANT TREATED POPLIN OUTER LAYER, SPACER MATERIAL INTERMEDIATE LAYER, AND TEE SHIRT INNER LAYER) AFTER EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Station Location and Ensemble	Pig No.	Radiant Exposure	Burn Damage to Skin Indicated at Examination 24 Hours after Exposure	Damage to Uniform Ensemble
		cal/cm^2		
64-HWS-1	81	21	No burn.	Cotton poplin destroyed, spacer destroyed with melted edges, tee shirt intact but scorched.
64-HWS-2	69	21	No burn.	Cotton poplin destroyed, spacer melted, tee shirt intact but scorched.
64-HWS-3	158	21	Small 2+ on lower rear leg.	Cotton poplin destroyed, spacer destroyed with melted edges, tee shirt scorched with spotty char.
64-HWS-4	50	21	4+ areas with 1-3+ and 1-2+ on leg.	Cotton poplin destroyed, spacer destroyed and melted edges, tee shirt charred.
75-HWS-1	134	14.5	No burn	Cotton poplin destroyed, spacer destroyed, tee shirt intact but scorched
75-HWS-2	96	14.5	1+ patchy on side, area of 3+ and 2+ on leg.	Cotton poplin destroyed, spacer destroyed, tee shirt intact but scorched.
75-HWS-3	150	14.5	Two small areas 2+.	Cotton poplin destroyed, spacer destroyed, tee shirt intact but scorched.
75-HWS-4	151	14.5	No burn.	Cotton poplin destroyed, spacer destroyed, tee shirt charred.
90-HWS-1	58	10	No burn.	Cotton poplin destroyed, spacer intact, tee shirt stained.
90-HWS-2	105	10	Diffuse 1+ with occasional 2+ areas, large areas of no burn.	Cotton poplin destroyed, spacer essentially destroyed, tee shirt stained.
90-HWS-3	62	10	No burn except questionable small 4+ area on shoulder.	Cotton poplin destroyed, spacer partially destroyed, tee shirt stained.
90-HWS-4	119	10	Background 1+ with three 2+ areas.	Cotton poplin destroyed, spacer partially destroyed, tee shirt stained.

TABLE 8.4 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT 3,930-FOOT STATION, SHOT WILSON

Laboratory values are for 17.5 cal/cm² and a t_m of 0.11 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	3.5	114	95	−17
2	Uncovered, blackened	3.5	168	116	−31
3	Poplin and sheeting in contact	1.7	30 to 60	51	—
4	Gray sateen and sheeting in contact	1.7	30 to 60	38	—

TABLE 8.5 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT 7,500-FOOT STATION, SHOT PRISCILLA

Laboratory values are for 15.0 cal/cm² and a t_m of 0.20 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	100	93	−7
2		3.5	100	94	−6
3	Blackening	3.5	140	115	−18
4	Poplin and	0.9	30 to 60	53	—
5	sheeting in contact	7.5	30 to 60	71	—
6	Gray sateen	0.9	30 to 60	77	—
7	and sheeting	0.9	30 to 60	46	—
8	in contact	7.5	30 to 60	47	—
9	Poplin and	0.9	10*	16	—
10	sheeting	1.7	12	19	—
11	spaced 5 mm	3.5	30 to 60	25	—
12		7.5	30 to 60	30	—
13	Gray sateen	0.9	20*	14	—
14	and sheeting	1.7	28	20	—
15	spaced 5 mm	3.5	30 to 60	22	—
16		7.5	30 to 60	22	—

* Lab temperature rise maxima are critically dependent on completion of combustion. Differences in ignition and not maximum temperature rise are significant in these situations.

TABLE 8.6 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT THE 12,150-FOOT STATION, SHOT PRISCILLA

Laboratory values are for 6.5 cal/cm² and a t_m of 0.20 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	42	*	—
2		3.5	42	*	—
3	Blackening	0.9	59	50	−15
4		3.5	59	*	—
5	Poplin and	0.9	21	*	—
6	sheeting	1.7	24	26	+8
7	in contact	3.5	24	25	+4
8		7.5	24	*	—
9	Gray sateen	0.9	22	25	+14
10	and sheeting	1.7	24	26	+8
11	in contact	3.5	24	24	0
12		7.5	24	*	—
13	Poplin and	0.9	2	*	—
14	sheeting	7.5	4	*	—
	spaced 5 mm				
15	Sateen and	0.9	2	*	—
	sheeting	7.5	5	*	—
	spaced 5 mm				

* Temperatures were not recorded.

TABLE 8.7 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AND RESPONSE OF PIGS AT THE 7,500-FOOT AND 12,150-FOOT STATIONS, SHOT PRISCILLA

Specimen		Radiant Exposure	Burn Assessment	Skin Simulant		Initial Skin Temperature
Pig Covering	Pig No.			Temperature Rise Maximum	Predicted Burn Severity	
		cal/cm²		C		C
Bare	1	6.5	1+ mild	—	—	—
	2		1+ mild			36
	3		No burn			31
	1	15	3+	93	In excess	—
	2		2+		of 3+	—
	3		3+			—
Poplin and	1	6.5	1+ severe	25	2+ mild	—
sheeting	2		No burn		2+ mild	38
in contact	3		1+ mild			36
	1	15	3+	60	In excess	—
	2		1+ mild		of 3+	—
	3		2+			—
Poplin and	1	6.5	1+ mild	—	—	—
sheeting	2		No burn			—
spaced 5 mm	3		1+ mild to			—
			no burn			—
	1	15	3+	27	In excess	—
	2		No burn		of 2+	—
	3		No burn			

TABLE 8.8 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT 10,500-FOOT STATION, SHOT HOOD

Laboratory values are for 16.3 cal/cm² and a t_m of 0.27 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	105	81	-23
2		3.5	105	75	-29
3	Blackening	0.9	142	113	-20
4		3.5	142	114	-20
5	Poplin and	0.9	30 to 60	47	—
6	sheeting in contact	7.5	30 to 60	71	—
7	Gray sateen	0.9	30 to 60	46	—
8	and sheeting in contact	7.5	30 to 60	53	—
9	Poplin and	0.9	10*	5	—
10	sheeting	1.7	12	19	—
11	spaced 5 mm	1.7	12	17	—
12		1.7	12	25	—
13		3.5	30 to 60	27	—
14		7.5	30 to 60	34	—
15	Gray sateen	0.9	20*	14	—
16	and sheeting	1.7	28	20	—
17	spaced 5 mm	1.7	28	22	—
18		3.5	30 to 60	30	—
19		7.5	30 to 60	33	—

* Lab temperature rises are critically dependent on amount of cloth actually burned. Differences in ignition are important here rather than temperature rises.

TABLE 8.9 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT THE 10,500-FOOT STATION, SCREENED EXPOSURES, SHOT HOOD

Laboratory values are for 4.0 cal/cm² and a t_m of 0.27 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	26.3	25.2	-4
2		3.5	26.3	25.8	-2
3	Blackening	0.9	35.3	40	-13
4		3.5	35.3	40	-13
5	Poplin and	0.9	14	16	+14
6	sheeting	1.7	15	21	+40
7	in contact	1.7	15	17	+13
8		1.7	15	21	+40
9		3.5	15	22	+46
10		7.5	15	23	+53
11	Gray sateen	0.9	14	19	+35
12	and sheeting	1.7	15.5	21	+39
13	in contact	1.7	15.5	22	+42
14		3.5	15.5	20	+32
15		7.5	15.5	24	+55
16	Poplin and	0.9	2	3	—
17	sheeting spaced 5 mm	7.5	4	4	—
18	Gray sateen	0.9	2	1.5	—
19	and sheeting spaced 5 mm	7.5	5	5	—

TABLE 8.10 EFFECTS ON STANDARD-REFERENCE MATERIALS OF EXPOSURE TO LABORATORY CARBON-ARC SOURCE OF THERMAL RADIATION

Material	Density	Thickness	Diameter of Irradiated Area	Critical Charring	Radiant Exposure Ignition or Afterglow
		mils	cm	cal/cm²	cal/cm²
Alpha Cellulose paper, black	0.75	2.1	0.9	1.8	3.5
Alpha Cellulose paper, black	0.75	4.1	0.9	3.0	6.1
Alpha Cellulose paper, black	0.75	6.1	0.9	4.1	7.9
Alpha Cellulose paper, black	0.75	8.3	0.9	5.2	9.4
Alpha Cellulose paper, black	0.75	20.3	0.9	5.5	10.0
Alpha Cellulose paper, black	0.75	31.5	0.9	5.7	27.0
Alpha Cellulose paper, black	0.55	30.3	0.9	3.9	19.0
Cotton Sateen, deep black, 9 oz/yd²			0.9	6.4	12.0
Cotton Poplin, Shade 116, 5 oz/yd²			0.9	9.2	17.0

TABLE 8.11 EFFECTS OF THERMAL RADIATION ON STANDARD-REFERENCE MATERIALS AT THE 6,450-FOOT STATION, SHOT PRISCILLA

Material	Diameter of Aperture	Effect Predicted from Lab Data	Observed Effect	Lab Radiant Exposure for Observed Effect
	cm			cal/cm²
Poplin, Shade 116, 5 oz/yd²	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain,* ignition probable † in all apertures	17
Alpha cellulose, black, density 0.55, thickness 30.3 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain,* ignition improbable ‡ in all apertures	19
Alpha cellulose, black, density 0.75, thickness 31.5 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain,* ignition improbable ‡ in all apertures	5.7 to 27

* Observation of charring certain, based on charred edges or shreds around aperture.

† Observation of ignition probable based on material being removed cleanly up to aperture edge with sooty residue under aperture plate.

‡ Observation of ignition improbable based on ragged edges and shreds of material left in aperture.

TABLE 8.12 EFFECTS OF THERMAL RADIATION ON STANDARD-REFERENCE MATERIALS AT THE 7,500-FOOT STATION, SHOT PRISCILLA

$Q \simeq 15$ cal/cm²

Material	Diameter of Aperture	Effect Predicted from Lab. Data	Observed Effect	Lab. Radiant Exposure for Observed Effect
	cm			cal cm²
Sateen dark gray, 9 oz yd²	0.9 1.5 3.5 3.5 (edge) 7 5	Ignition	Charring certain, * ignition probable † in all apertures	12
Poplin, Shade 116, 5 oz/yd²	0 9 1.5 3 5 3 5 (edge) 7.5	Charring	Charring certain, * ignition probable † in all apertures	17
Alpha cellulose, black, density 0.35 thickness 30 3 mils	0 9 1.5 3 5 3 5 (edge) 7 5	Charring	Charring certain*, ignition improbable ‡	3 9 to 19

* Observation of charring certain based on charred edges or shreds around aperture

† Observation of ignition probable based on material being removed cleanly up to aperture edge, with sooty residue under aperture plate

‡ Observation of ignition improbable based on ragged edges and shreds of material left in aperture

TABLE 8.13 EFFECTS OF THERMAL RADIATION ON STANDARD-REFERENCE MATERIALS AT THE 8,400-FOOT STATION, SHOT PRISCILLA

$Q \simeq 13$ cal/cm²

Material	Diameter of Aperture	Effect Predicted from Lab. Data	Observed Effect	Lab Radiant Exposure for Observed Effect
	cm			cal/cm²
Alpha cellulose, black, density 0.75 thickness 20.3 mils	0.9 1.5 3.5 3.5 (edge) 7 5	Ignition	Charring certain, * ignition improbable, † in all apertures	5 5 to 10
Sateen, dark gray, 9 oz/yd²	0.9 1.5 3.5 3 5 (edge) 7.5	Ignition	Charring certain * ignition uncertain ‡ in all apertures	6 4 to 12
Poplin, Shade 116, 5 oz/yd²	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain * ignition improbable ‡ in all apertures	9 2 to 17

* Observation of charring certain based on charred edges or shreds around aperture.

† Observation of ignition improbable based on ragged edges and shreds of material left in aperture

‡ Observation of ignition uncertain based on occasional unburned threads protruding from aperture edge.

TABLE 8.14 EFFECTS OF THERMAL RADIATION ON STANDARD-REFERENCE MATERIALS AT THE 9,000-FOOT STATION, SHOT PRISCILLA

$Q \approx 10\ cal/cm^2$

Material	Diameter of Aperture	Effect Predicted from Lab Data	Observed Effect	Lab. Radiant Exposure for Observed Effect
	cm			cal/cm^2
Alpha cellulose, black, density 0.75 thickness 8 3 mils	0 9 1.5 3.5 3.5 (edge) 7 5	Ignition	Charring certain,* ignition probable † in all apertures	9.4
Alpha cellulose, black, density 0 75, thickness 20 3 mils	0 9 1.5 3 5 3.5 (edge) 7.5	Ignition (critical)	Charring certain* no ignition ‡ in all apertures	5.5 to 10
Sateen, dark gray 9 oz yd²	0 9	Charring	Charring certain* ignition improbable ¶	6 4 to 12
	1 5		charring certain* ignition uncertain §	
	3.5		charring certain* ignition uncertain §	
	3 5 (edge)		charring certain* ignition probable †	
	7.5		charring certain* ignition uncertain §	

* Observation of charring certain based on charred edges or shreds around aperture

† Observation of ignition probable based on material being removed cleanly up to aperture edge, with sooty residue under aperture

‡ Observation of no ignition based on large residue of partially charred, unconsumed material

¶ Observation of ignition improbable based on ragged edges and shreds of material left in aperture.

§ Observation of ignition uncertain based on occasional unburned threads protruding from aperture edge

TABLE 8.15 EFFECTS OF THERMAL RADIATION ON STANDARD-REFERENCE MATERIALS AT THE 10,000-FOOT STATION, SHOT PRISCILLA

$Q \approx 8.5\ cal/cm^2$

Material	Diameter of Aperture	Effect Predicted from Lab Data	Observed Effect	Lab. Radiant Exposure for Observed Effect
	cm			cal. cm²
Alpha cellulose, black, density 0 75, thickness 4 1 mils	0 9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain* ignition probable†	6.1
Alpha cellulose, black, density 0 75 thickness 6 1 mils	0 9 1.5 3.5 3.5 (edge) 7 5	Ignition	Charring certain* ignition probable † in all apertures	7 9
Alpha cellulose, black, density 0 75, thickness 8 3 mils	0 9 1 5 3.5 3.5 (edge) 7.5	Charring	Charring certain* ignition improbable ‡ in all apertures	5 2 to 9 4

* Observation of charring certain based on charred edges or shreds around aperture.

† Observation of ignition probable based on material being removed cleanly up to aperture edge with sooty residue under aperture plate.

‡ Observation of ignition improbable based on ragged edges and shreds of material left in aperture.

TABLE 8.16 EFFECTS OF THERMAL RADIATION ON STANDARD-REFERENCE MATERIALS AT THE 12,150-FOOT STATION, SHOT PRISCILLA

Q = 6.5 cal/cm²

Material	Diameter of Aperture	Effect Predicted from Lab. Data	Observed Effect	Lab. Radiant Exposure for Observed Effect
	cm			cal/cm²
Alpha cellulose, black, density 0.75, thickness 4.1 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain* ignition probable† in all apertures	8.1
Alpha cellulose, black, density 0.75, thickness 6.1 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain* ignition improbable‡ in all apertures	4.1 to 7.9
Alpha cellulose, black, density 0.75, thickness 8.3 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain* ignition improbable‡ in all apertures	5.2 to 9.4

* Observation of charring certain based on charred edges or shreds around aperture.

† Observation of ignition probable based on material being removed cleanly up to aperture edges with sooty residue under aperture plate.

‡ Observation of ignition improbable based on ragged edges and shreds of material left in aperture.

TABLE 8.17 THERMAL RADIATION, SHOT WILSON, 3,965 FEET

Foil Meter		Radiometer			Calorimeter			Copper Plate			
Screen Transmission	Radiant Exposure	Q	H_m	t_m	Q	H_m	t_m	Pellet Q	Electrical Q	Electrical H_m	Electrical t_m
	cal/cm²	cal/cm²	(cal/cm²)/sec	sec	cal/cm²	(cal/cm²)/sec	sec	cal/cm²	cal/cm²	(cal/cm²)/sec	sec
—	21	17.6	69	0.105	17.6	59	0.114	15	15.4	54	0.114
—	22	17.5	65	0.107	16.6	55	0.110	14	11.2*	52	0.105
0.45	15	—	—	—	—	—	—	13	13.2†	55	0.104
0.45	15	—	—	—	—	—	—	15	—	—	—

* Under screen with a 0.14 transmission.

† Under screen with a 0.037 transmission.

TABLE 8.18 THERMAL RADIATION, SHOT PRISCILLA, PROJECT 8.1

Slant Distance	Recording Meter	Copper Plate Meter, Pellets	Foil Meter Screen Transmission	Foil Meter Radiant Exposure
ft	cal/cm²	cal/cm²		cal/cm²
5,850	—	24	—	23
	—	—	0.095	16
6,490	—	21	—	21
	—	—	0.095	9
7,540	16.3	15	—	19
	13.8	—	0.145	10
9,020	—	10	—	8
	—	—	0.145	6.5
12,170	6.7	4.9	—	5
	6.4	—	0.48	4

TABLE 8.19 THERMAL RADIATION, SHOT PRISCILLA, PROJECT 4.1 STATIONS

Slant Distance	Copper Plate Meter: Screen Transmission	Copper Plate Meter: Radiant Exposure	Foil Meter: Screen Transmission	Foil Meter: Radiant Exposure	Most Probable Value
ft		cal/cm²		cal/cm²	cal/cm²
2,720	0.55	92 *	—	—	90
	—	< 121	—	—	—
2,820	0.55	76 *	—	†	75
	—	< 91	—	—	—
3,085	—	80 *	—	—	75
	0.55	70	—	—	—
3,995	—	—	—	—	—
4,210	—	60	0.095	49	60
	—	—	0.048	47	—
4,480	—	40	—	—	40
4,820	—	45	—	—	45
5,390	—	—	—	—	—
6,180	—	22	—	21	21
	—	—	0.095	12	—
7,860	—	14	—	—	15
	—	17	—	—	—
9,520	—	—	—	—	—

* The windows of these instruments were broken and sand was embedded in the receiving plate.

† Instruments were destroyed by missiles.

TABLE 8.20 THERMAL RADIATION, SHOT PRISCILLA, PROJECT 8.2 STATIONS

Slant Distance	Copper Plate Meter: Pellet Q	Copper Plate Meter: Electrical Q	Copper Plate Meter: Electrical H_m	Copper Plate Meter: Electrical t_m	Foil Meter: Screen Transmission	Foil Meter: Q	Radiometer: Q	Radiometer: H_m	Radiometer: t_m	Calorimeter: Q	Calorimeter: H_m	Calorimeter: t_m
ft	cal/cm²	cal/cm²	(cal/cm²)/sec	sec		cal/cm²	cal/cm²	(cal/cm²)/sec	sec	cal/cm²	(cal/cm²)/sec	sec
6,490	24	—	—	—	—	—	—	—	—	—	—	—
	21	—	—	—	—	—	—	—	—	—	—	—
7,540	18	18.9 *	43 *	0.20	—	21	12.0	27	0.16	16.3	26.5	0.20
	17	13.2	28	0.20	0.15	8	—	—	—	13.8	27.5	0.21
8,440	13	—	—	—	—	9	—	—	—	—	—	—
	—	—	—	—	0.15	8	—	—	—	—	—	—
9,030	10	—	—	—	—	—	—	—	—	—	—	—
10,025	8	—	—	—	—	6	—	—	—	—	—	—
	—	—	—	—	0.15	6.5	—	—	—	—	—	—
12,170	4.3	5.5	—	—	—	5	6.7	12.0	0.18	6.4	11	0.20
	5.3	—	—	—	0.46	4.5	—	—	—	—	—	—
	4.9	—	—	—	—	—	—	—	—	—	—	—
19,020	1.8	—	—	—	—	—	—	—	—	—	—	—
	1.8	—	—	—	—	—	—	—	—	—	—	—
27,000	0.89	—	—	—	—	—	—	—	—	—	—	—
	1.22	—	—	—	—	—	—	—	—	—	—	—
37,000	0.49	—	—	—	—	—	—	—	—	—	—	—
	0.49	—	—	—	—	—	—	—	—	—	—	—
50,000	0.45	—	—	—	—	—	—	—	—	—	—	—
	0.43	—	—	—	—	—	—	—	—	—	—	—

* Poor trace quality.

TABLE 8.21 THERMAL RADIATION, SHOT WILSON, PROJECT 4.1 STATIONS

Slant Distance	Copper Plate Meter: Screen Transmission	Copper Plate Meter: Radiant Exposure	Foil Meter: Screen Transmission	Foil Meter: Radiant Exposure
ft		cal/cm^2		cal/cm^2
2,590	0.48	29	—	—
	0.48	27	—	—
2,720	—	29	—	29
	—	31	0.073	34
2,920	—	23	—	—
	—	23	—	—
3,495	—	20	—	23
	—	21	0.14	19

TABLE 8.22 THERMAL RADIATION, SHOT HOOD

Radiometer			Calorimeter			Copper Plate Meter: Pellet	Copper Plate Meter: Electrical		
Q	H_m	t_m	Q	H_m	t_m	Q	Q	H_m	t_m
cal/cm^2	(cal/cm^2)/sec	sec	cal/cm^2	(cal/cm^2)/sec	sec	cal/cm^2	cal/cm^2	(cal/cm^2)/sec	sec
15.8	25	0.27	16.6	25	0.27	13.8†	13.0†	22	0.275
—	—	—	16.1	23	0.27	13.6	11.5	21	0.26
—	—	—	14.5*	24*	0.28	13.9	—	—	—
Under screen with skin-simulants:									
3.8	3.7	0.27	4.2	6.2	0.27	—	—	—	—
—	—	—	3.9	5.9	0.26	—	—	—	—

* With excluding tube.

† Corrected for 0.48 screen transmission.

TABLE 8.23 SPECIMEN INFORMATION

Nominal Slant Range	Design Criteria p, 10^3 psi	q, 10^3 psi	10^{11} N cm^2	Specimen	Diameter	Weight	Instrumentation	Location
feet					inches	pounds		
Shot Smoky								
…50	28	130	8.4	MI Steel Sphere (Type 2)	13	318	Peak pressure, inserts and intensity gages	Cable 2
…0	28	130	8.4	Insert Sphere	13.44	320	Inserts and intensity gages	Cable 2
…50	28	130	8.4	MI Sphere (Type 20)	13.44	230	Velocity-distance	Cable 2
…60	28	130	8.4	EI Cylinder	15 (7 feet long)	2,300	Two tape recorders peak pressure and velocity-distance	Tower
…50	6	30	3	EI Steel Sphere (Type 2)	13.44	247	One tape recorder and velocity-distance	Cable 4
…50	6	30	3	MI Steel Sphere (Type 3)	13	318	Peak pressure, inserts and intensity gages	Cable 4
…0	6	30	3	Insert Sphere	13.44	321	Inserts and intensity gages	Cable 4
…0	6	30	3	MI Bowling Ball	5	4	Intensity gage and inserts	Cable 1
…00	3.5	17	2.1	Iron Sphere	10	149	—	Cable 5
…00	3.5	17	2.1	Zinc Insert Sphere	10	135	—	Cable 5
…00	3.5	17	2.1	Titanium Sphere	8	44	—	Cable 5
…00	3.5	17	2.1	Molybdenum Sphere	8	99	—	Cable 2
…00	3.5	17	2.1	Stainless Steel Sphere	8	74	—	Cable 1
…00	3.5	17	2.1	Copper Sphere	8	87	—	Cable 5
…00	3.5	17	2.1	Plastic Sphere 91LD	8	17	—	Cable 3
…0	2.2	8.5	1.5	EI Steel Sphere (Type 3)	13.44	247	One tape recorder and velocity-distance	Cable 1
…50	2.2	8.5	1.5	MI Steel Sphere (Type 4)	13	318	Peak pressure, inserts and intensity gages	Cable 1
…50	2.2	8.5	1.5	Insert Sphere	13.44	320	Inserts and intensity gages	Cable 1
…50	1.5	4	1.2	Zinc Sphere	10	135	—	Cable 5
…0	1.5	4	1.2	Zinc Insert Sphere	10	133	—	Cable 5
…400	1.5	4	1.2	MI Bowling Ball	5	4	Intensity gage and inserts	Cable 5
…50	1	2.5	0.93	Insert Cylinder	8 (40 inches long)	366	Inserts	Tower
…65	0.215	0.560	0.32	MI Sphere (Type 50)	13.44	38	Velocity-distance	Cable 1
[illegible]				Graphite Sphere	8	17	—	Ground
Shot Priscilla								
…10	0.215	0.550	0.29	EI Plastic Sphere	13.44	40	One tape recorder	Ground

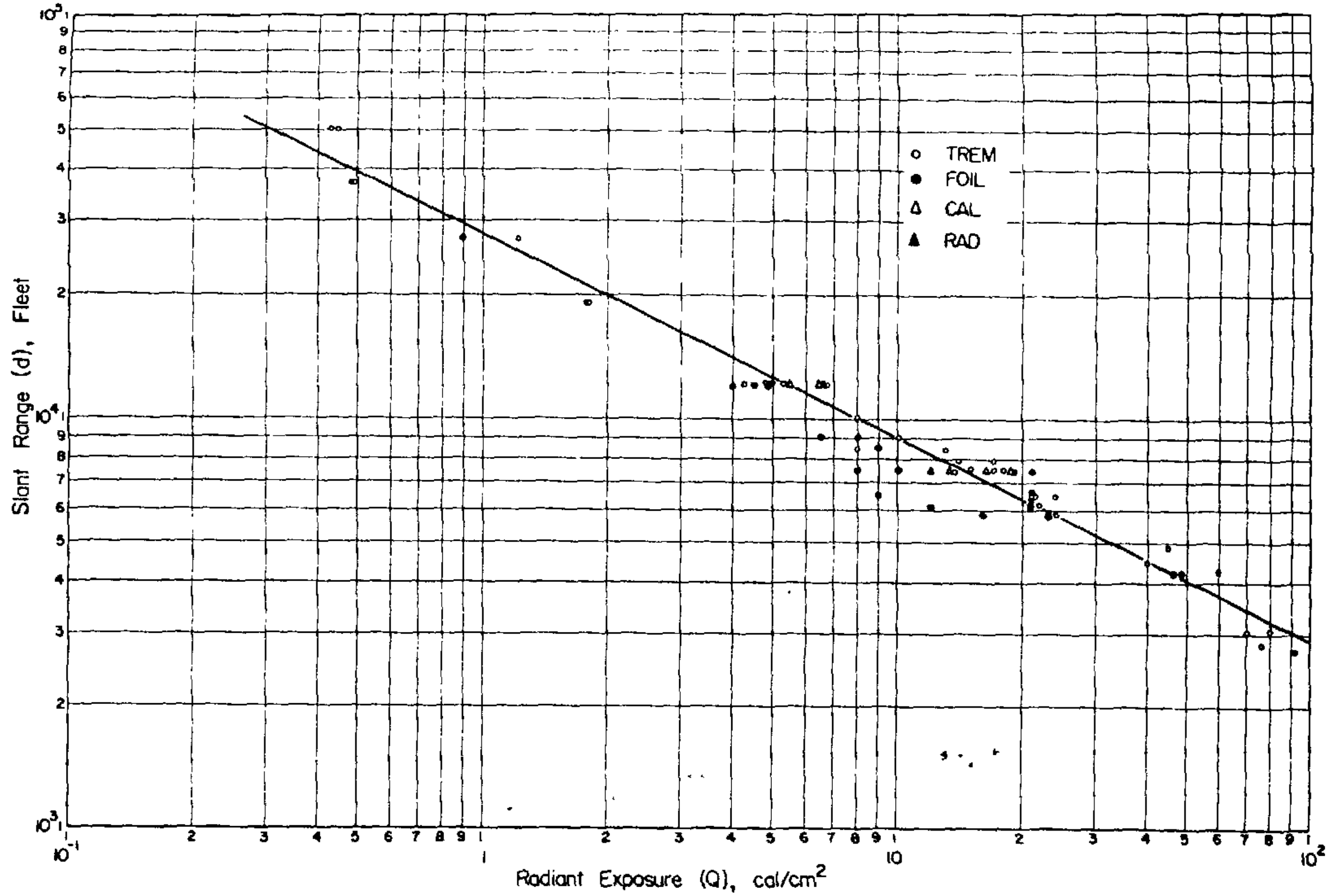


Figure 8.1 Basic thermal-radiation measurements, Shot Priscilla. Comparison of TREM with other techniques.

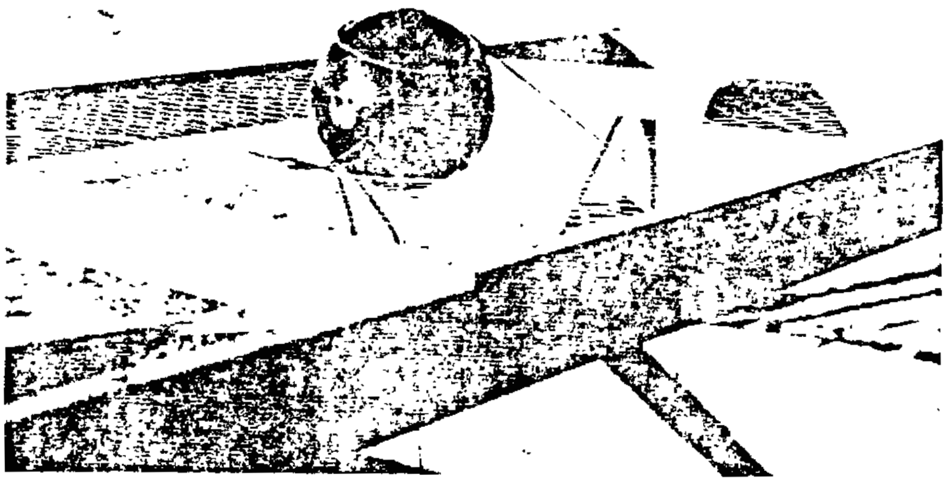


Figure 8.2 Exposure technique for electrically instrumented plastic sphere, Shot Priscilla.

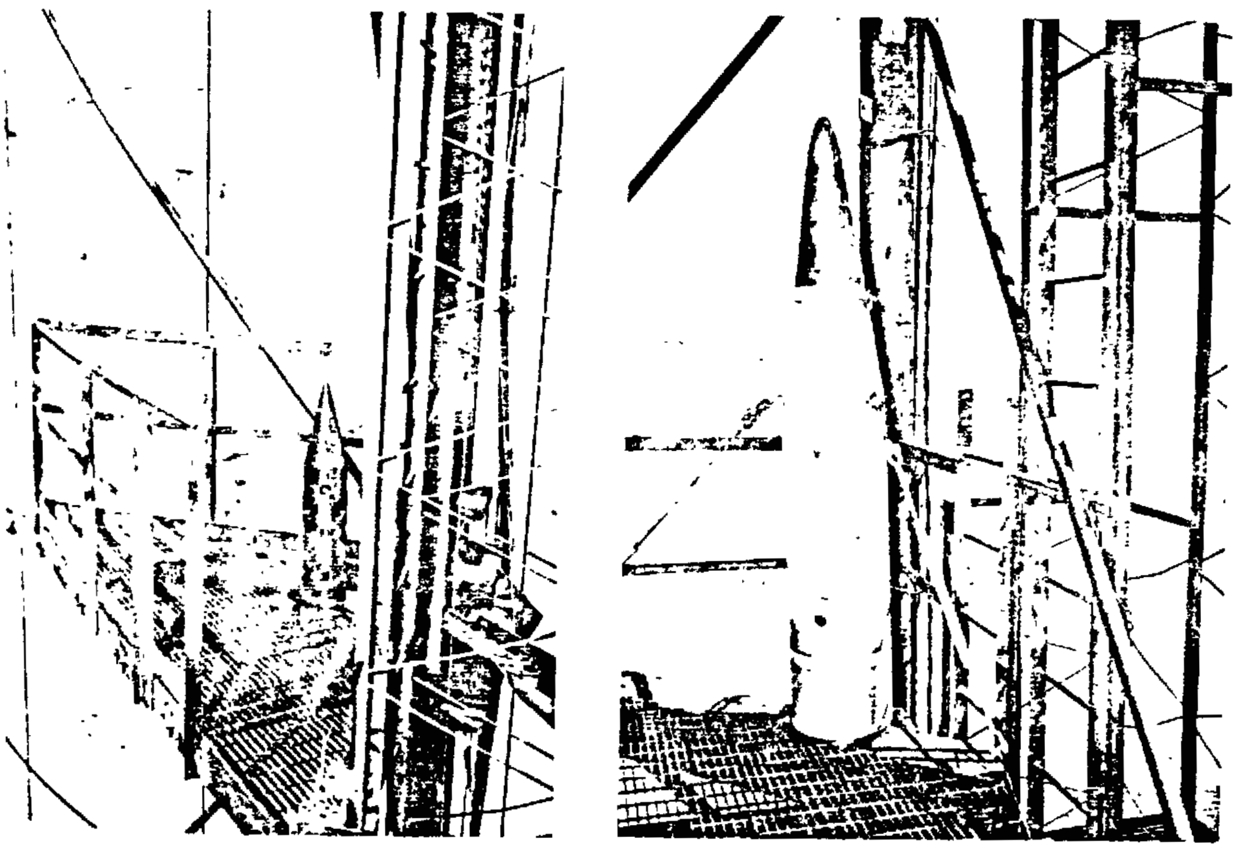


Figure 8.3 Exposure technique for cylinders, Shot Smoky.

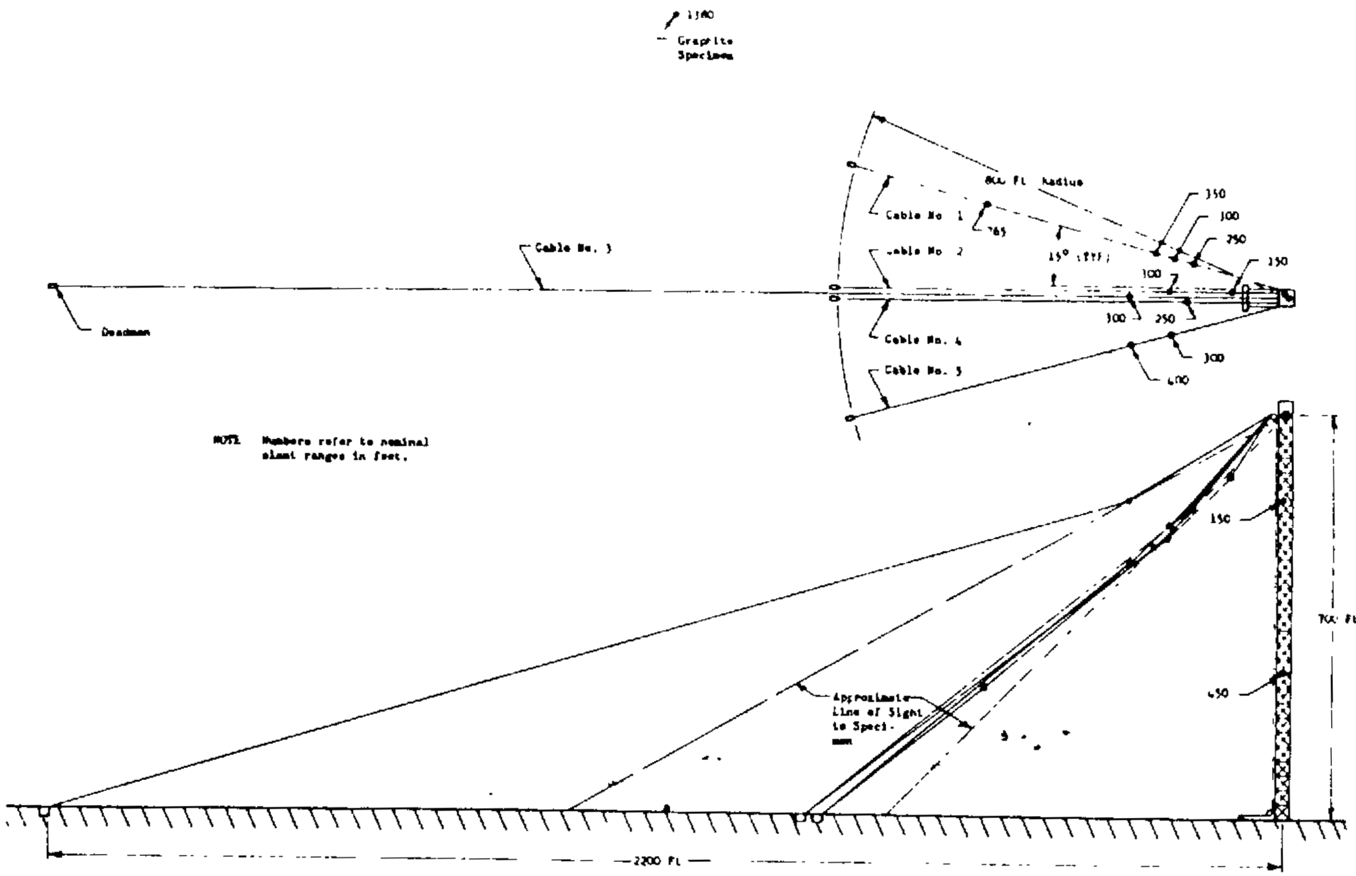


Figure 8.4 Exposure technique for specimens, Shot Smoky.

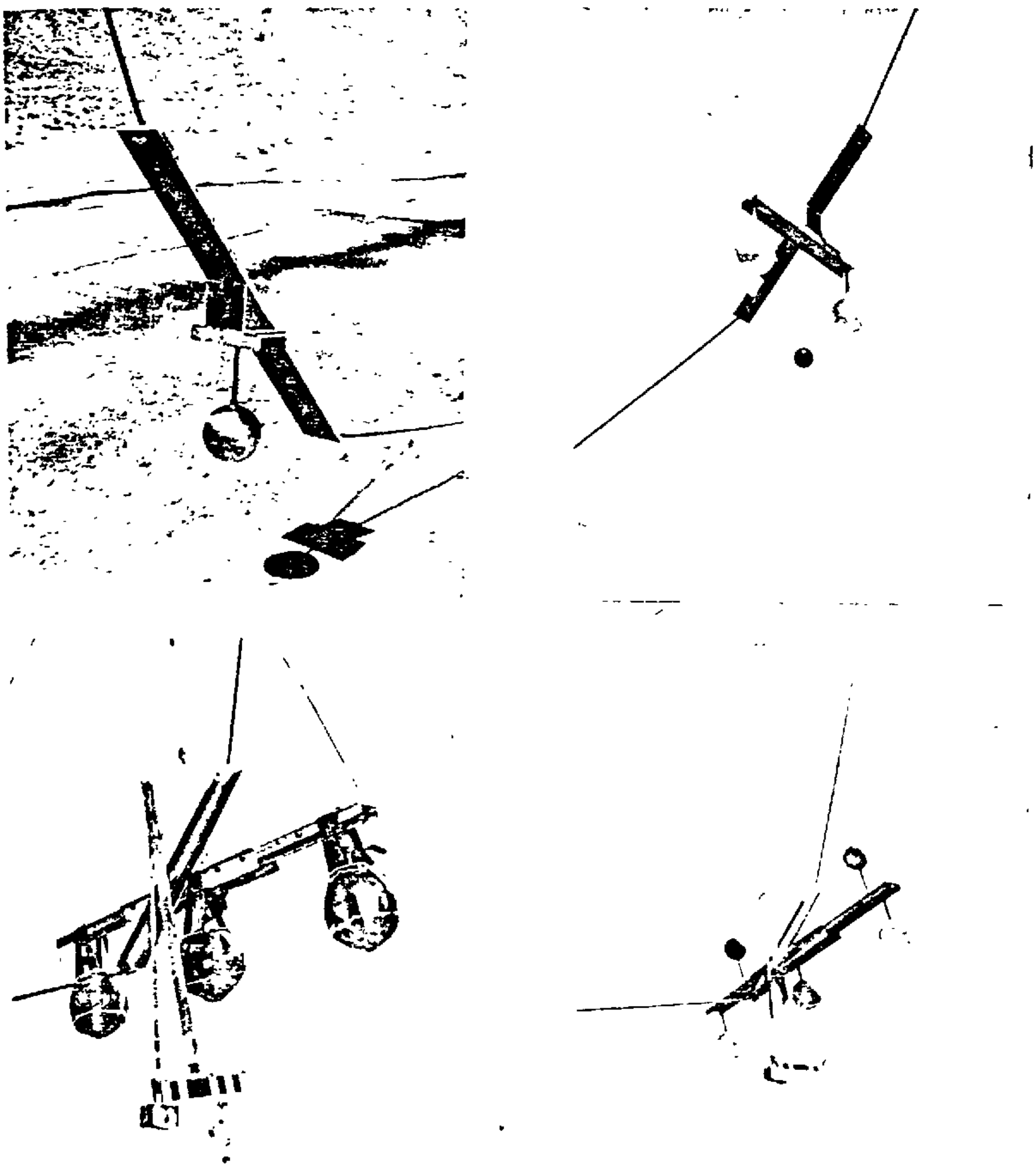


Figure 8.5 Typical specimen arrays, Shot Smoky.

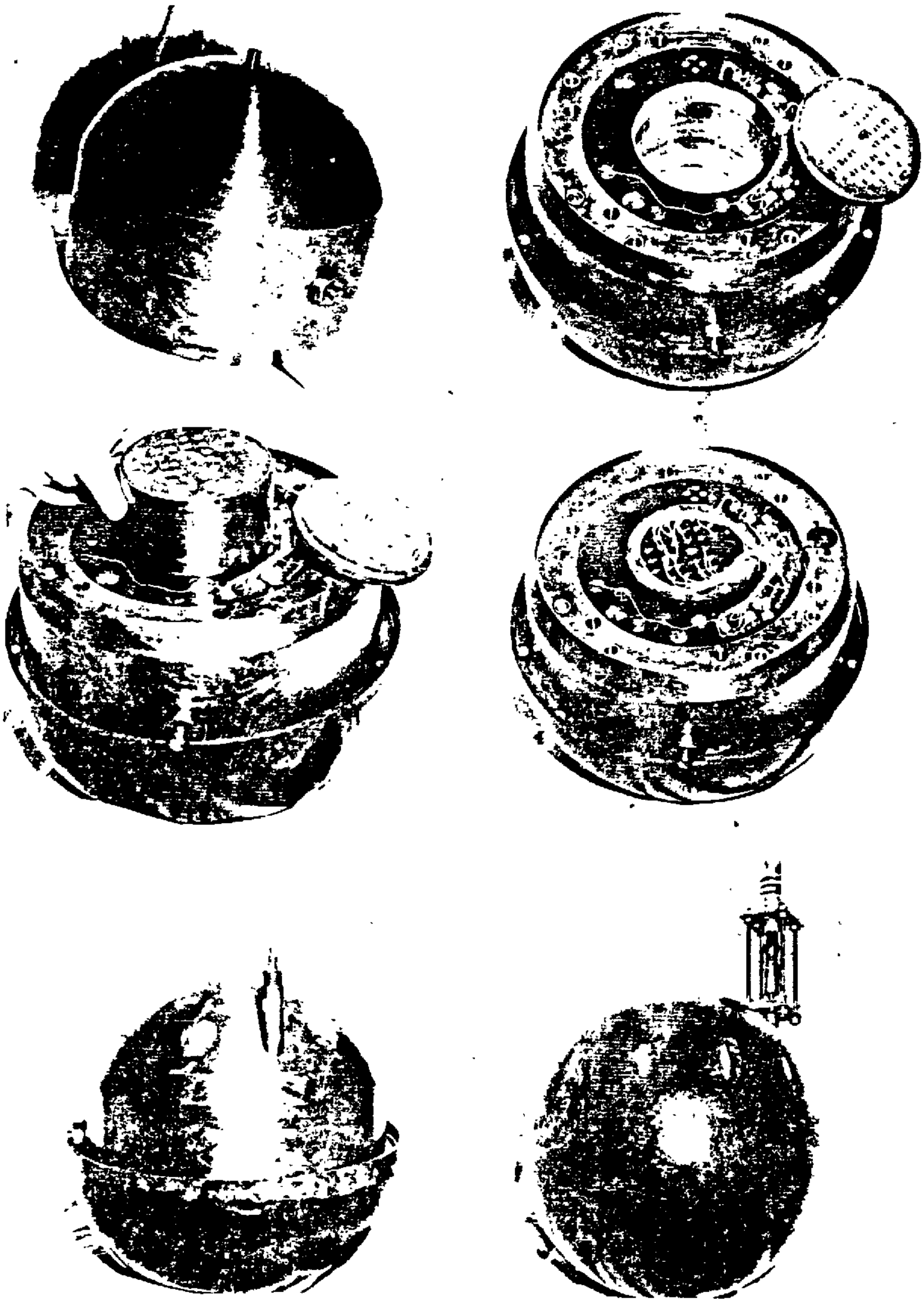


Figure 8.6 Assembly stages, electrically instrumented steel sphere.

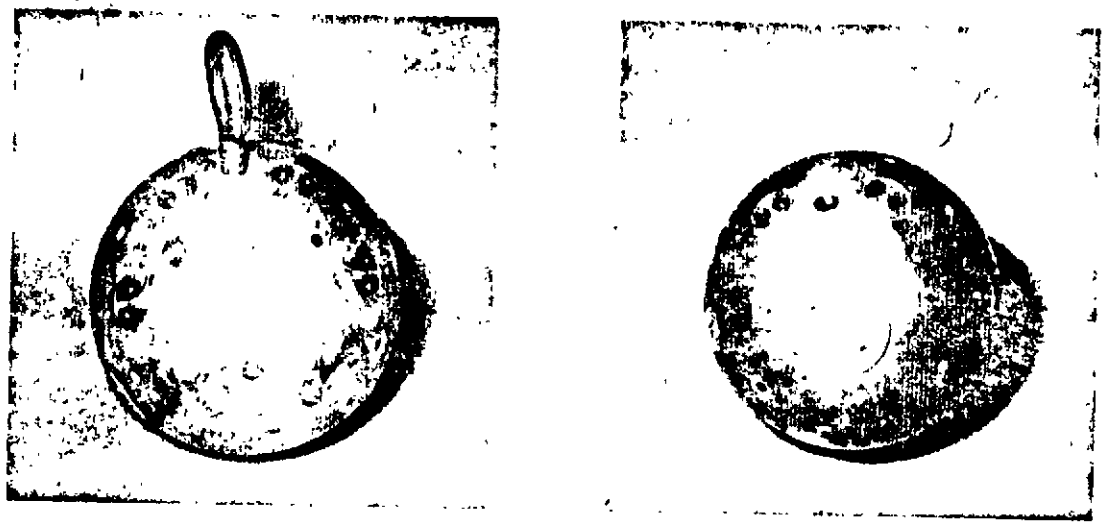
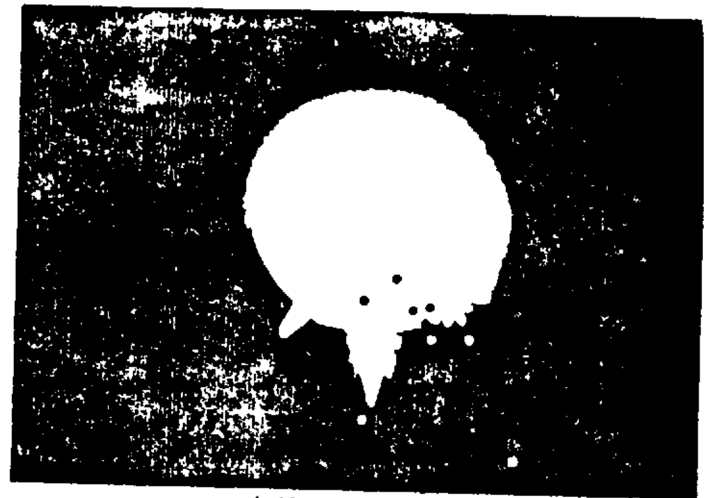
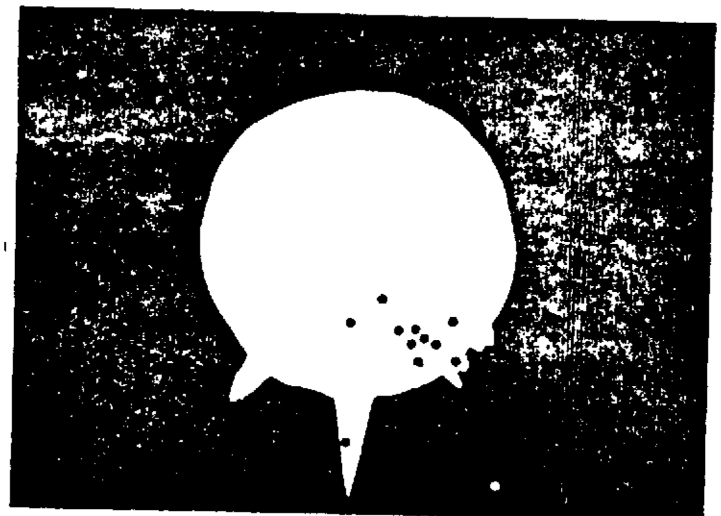


Figure 8.7 Typical mechanically instrumented steel sphere, Shot Smoky.

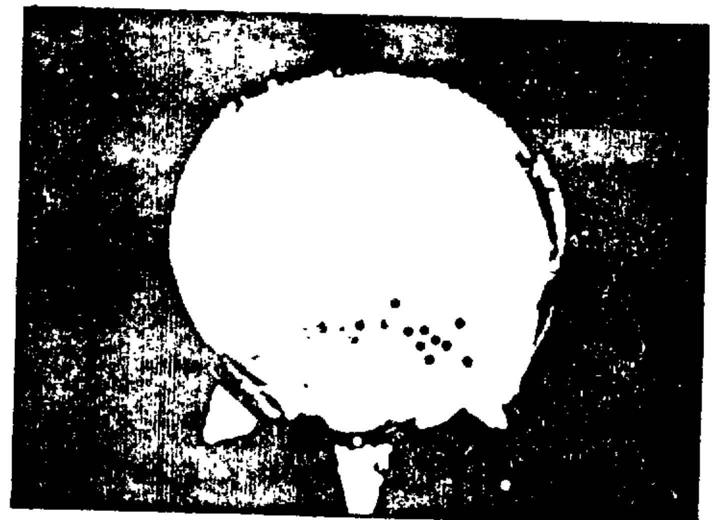
1.98 MILLISECONDS



6.22 MILLISECONDS



12.6 MILLISECONDS



24.9 MILLISECONDS

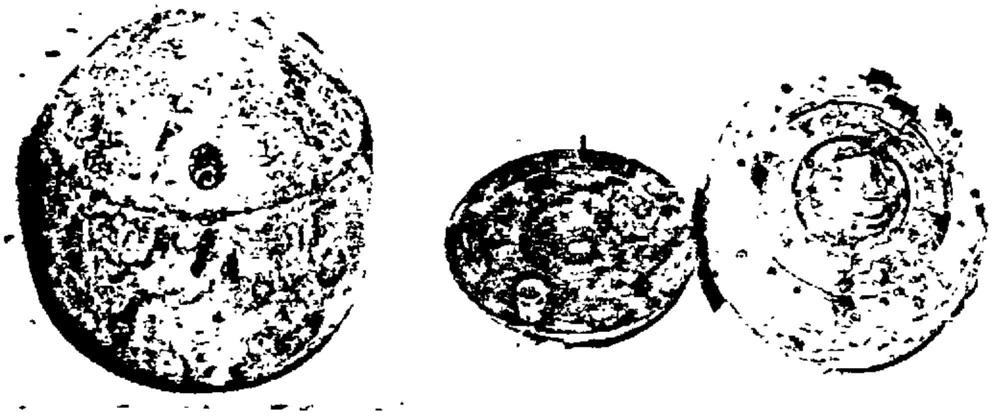


Figure 8.9 Electrically instrumented steel sphere, Type 2, slant range 250 feet.

Figure 8.10 Plastic shell sections from electrically instrumented steel sphere, Type 3, slant range 350 feet.

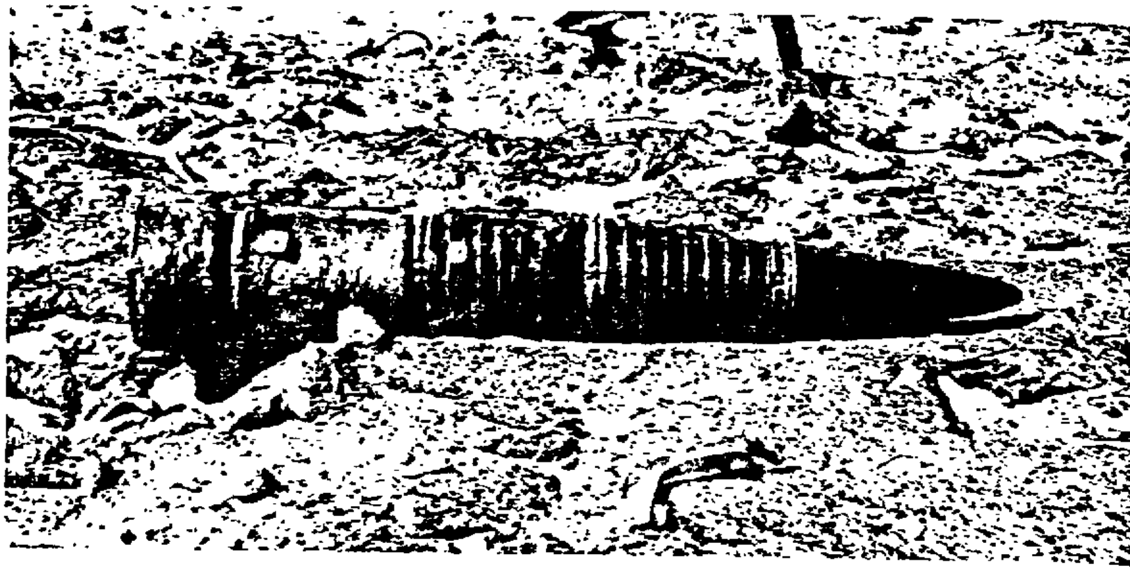
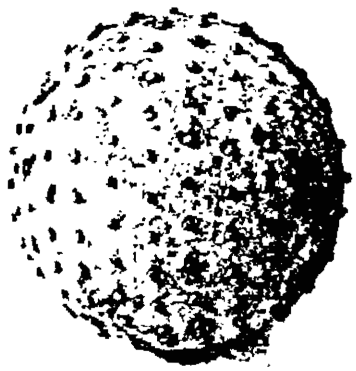
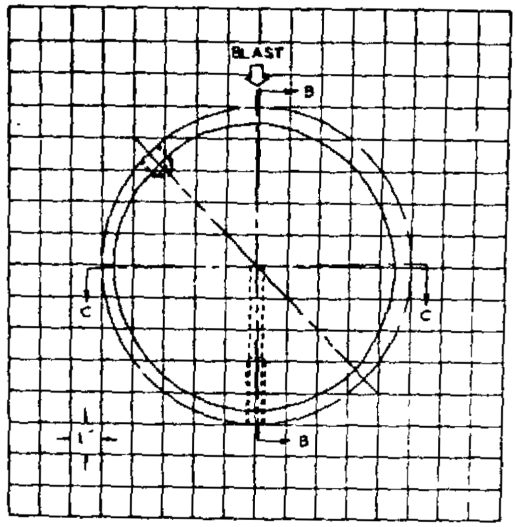


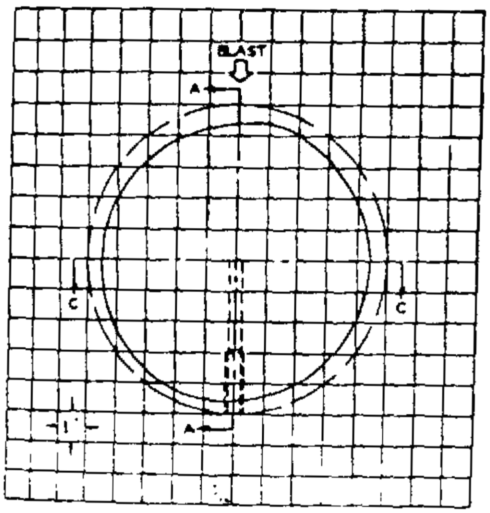
Figure 8.11 Postshot recovery photograph of electrically instrumented steel cylinder, slant range 160 feet.

Figure 8.12 Postshot photographs of mechanically instrumented bowling ball, Specimen No. 21, slant range 400 feet.

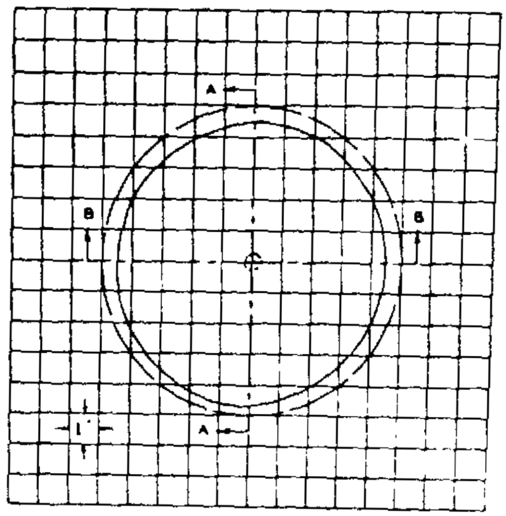




Section AA



Section BB



Section CC

Figure 8.13 Postshot view and profile drawings of zinc insert sphere, Specimen No. 20, slant range 400 feet.

Chapter 9

SUPPORT PHOTOGRAPHY

This program was primarily of a support nature and consisted of a single project concerned with (1) technical photographic support of the military-effect programs, (2) documentation of the overall program and production of a military-effect motion picture, (3) documentation of the detonations for release through the Joint Office of Test Information and for historical purposes, and (4) general photographic support of Department of Defense (DOD) projects.

For the purposes of technical photographic support, Program 9 provided camera instrumentation for the following shots and DOD projects.

Shot	Project	Purpose
Franklin	5.2	Blimp effects
	6.3	Cloud tracking
Lassen	2.10	Kytoon position and effects
Wilson	2.10	Kytoon position and effects
	6.3	Cloud tracking
Priscilla	1.3	Shock wave photography
	3.6	Dome deflection
	4.1	Biomedical photography
	6.3	Cloud tracking
	8.1	Thermal effects
	8.2	Skin simulant effects
Hood	2.1	Cloud tracking
	8.2	Skin simulant effects
John	9.1	Fireball photography
	9.1	Cloud tracking
Owens	1.2	Rocket launcher and canister positions
	2.10	Kytoon positions
	6.3	Cloud tracking
Smoky	1.8	Shock wave photography
	1.8	Tank model photography
	6.3	Cloud tracking
Stokes	5.2	Blimp effects

For the purposes of documentation of the weapon-effect programs and the production of a military-effect motion picture report, approximately 75,000 feet of color motion-picture film were taken at the test site. This footage was planned and accomplished to cover the was produced.

To document the detonations for historical purposes and for release to the press through the Joint Office of Test Information, both color and black-and-white coverage of each detonation was accomplished from an airborne camera station and a forward-area manned camera station. This coverage consisted of still and motion-picture photography. By the use of laboratory facilities established at the test site, it was possible to process, classify, and release coverage to the press within 2 hours after each detonation.

In general support of the participating DOD projects, approximately 5,000 still photographs were made at the test site. Immediate prints were produced for use of the projects. Laboratory facilities were also used to process microfile and oscillograph records as required.

Program 9 fulfilled its overall mission in providing photographic support to the various DOD projects. Although some photography was lost because of unusually high pressures and radiation levels, which destroyed some equipment and fogged some film, the overall technical photographic effort can be considered successful.

Appendix

PROJECT ABSTRACTS

A.1 PROGRAM 1: BLAST MEASUREMENTS

A.1.1 Project 1.1. Agency: Ballistic Research Laboratories. Report Title: Basic Airblast Phenomena, WT-1401. Project Officer: E. J. Bryant.

Surface level overpressures and dynamic pressures were measured during 14 shots of Operation Plumbbob. The information was obtained on (1) overpressure and dynamic pressure as a function of time and distance, (2) formation and history of precursor waveforms, (3) applicability of scaling laws for determining surface and near-surface pressure from high-altitude bursts, and (4) validity of the pressure-distance curve in the low-pressure region.

In these experiments, 223 overpressure-time gages and 57 dynamic pressure-time gages were used. These gages yielded 174 overpressure and 47 dynamic pressure records of good quality.

Shot Priscilla was the first test during which emphasis was placed on the high-pressure region. A sharp rising classical pressure-time wave was measured at 350 and 450 feet, and it was not until the third station at 650 feet that a precursor wave was observed. During Shot Priscilla, good comparison was obtained between the predicted blast wave parameters and the measured values.

Nine shots were instrumented for precursor waveform information, and precursors were observed on six of the nine. All precursor-producing shots provided waveform data in the desired region above 50 psi.

Ten self-recording, low-pressure gages were used to make surface and near-surface overpressure measurements at five stations during Shot John. Seven gages gave good pressure-time records, two recorded peak pressure, and one failed to record.

Measurements in the low-pressure region (0.1 to 1 psi) showed large variations in maximum pressure and indicated that temperature and wind velocity can substantially change a shock wave when the pressure is weak and the travel time is long.

A.1.2 Project 1.2. Agency: U. S. Naval Ordnance Laboratory. Report Title: Field Test of a System for Measuring Blast Phenomena by Airborne Gages, ITR-1402 (ITR considered final). Project Officer: P. Hanlon.

Project 1.2 participated in Operation Plumbbob in order to proof-test prototype airblast instrumentation for Operation Hardtack and to train personnel in handling this experiment under field conditions. The airblast systems consisted of (1) parachute-supported canisters containing self-recording mechanical pressure gages that were deployed by means of rockets and (2) balloon-supported pressure instrumentation.

Four fully instrumented rockets were fired successfully. With the exception of one, the rockets performed satisfactorily. The fourth rocket functioned normally through parachute deployment, at which time the afterbody over-rode the parachute and became entangled, causing an abnormally fast rate of descent. In spite of the malfunction, a pressure record was obtained. This type of malfunction can be corrected.

The test of the balloon system was limited as a result of the pretest loss of three of the four balloons. The limited experiment (one balloon was flown at a height of 200 feet above the surface supporting one gage at an altitude of 25 feet) was successful. However, in light of the experience gained, it is apparent this system must be modified. The load supported by the balloons must be reduced.

The pressure and recording equipment were used with both the balloon and rocket systems. Pressure-time records were obtained in all cases except one. In one of the rockets a pressure record was not obtained, due to a failure in the electrical system. There were several defects noted in the system, none of which are considered serious. The general performance of the system was satisfactory. It was concluded that the basic design was sound.

A.1.3 Project 1.3. Agency: Stanford Research Institute. Report Title: Air-Blast Phenomena in the High-Pressure Region, WT-1403. Project Officer: L. M. Swift.

The basic objective was to obtain data on the variation with time and ground range of overpressure and dynamic pressure resulting from a nuclear explosion. Particular emphasis was on phenomena in the regions of high pressure (above 50 psi) and disturbed (nonclassic) blast waves. A secondary objective was to provide detailed data on blast arrival time versus ground (or slant) range, especially at close-in ground ranges.

Surface level and aboveground static overpressures, near-surface differential pressures (pitot-tube), and near-surface total pressures were measured on a low-burst-height nuclear explosion (Shot Priscilla) 700 feet, 36.6 kt. Gages were placed at ground ranges from 450 feet to 4,500 feet, with a concentration of measurements in the high-pressure region. Blast switches, which measured arrival time only, were placed at several ranges, the closest at 100-foot range. Usable records were obtained on 39 of the 47 electronic channels.

A precursor wave formed near 500-foot ground range, and dissipated between 2,000 and 2,500 feet. Shot Priscilla shock velocity agrees with the ideal except between 500- and 2,000-foot ranges where it exceeds the ideal. Computed preshock arrival surface temperatures are significantly higher than those computed for Shot 12, Operation Teapot.

At high pressures, overpressures agree well with those predicted over an ideal surface, although surface maxima are depressed below the ideal curve. Maximum precursor overpressures out to about 1,000 feet are approximately one tenth the peak overpressure and decrease with ground range at about the same rate as the peak overpressure.

Total-head pressures obtained in the Mach reflection region agree with the ideal until 850 feet. From 850 to 2,500 feet, peak total pressure is significantly higher than the ideal.

Maximum differential pitot-tube pressures are higher than predicted over an ideal surface. Maximum differential pressure is computed from total-head pressure and overpressure measurements. Maximum dynamic (air-plus-dust) pressure computed from Mach number and surface overpressure is lower than ideal at close-in stations, agrees with ideal at mid-ranges, and exceeds ideal at 2,500 feet and beyond.

Differential pressure waveform classifications based on the degree of deviation from the corresponding overpressure waveform indicates that at close-in scaled ground ranges total-head pressure waveforms follow fairly closely those of the overpressure. The greatest deviations are concentrated between 450 and 900 feet scaled ground range and 100 and 300 feet scaled burst height.

Comparison of Hess' stagnation bubble theory with precursor phenomena suggests that this theory can be used to describe precursor formation.

A.1.4 Project 1.4. Agency: Stanford Research Institute. Report Title: Ground Acceleration, Stress, and *Strain at High Incident Overpressures, WT-1404. Project Officer: L. M. Swift.*

Project 1.4 objectives were to measure underground effects of a nuclear air burst (Shot Priscilla; 36.6 kt) as they vary with time, depth, and ground range, particularly in the region of high pressure; furnish, from these measurements, input data to other projects; and analyze these measurements with results of other tests. At 750 and 1,050 feet from ground zero, acceleration, stress, and strain measurements were made at several depths down through 50 feet, including two measurements each of horizontal acceleration and stress. At 450, 550, 650, 750, 850, 1,050, and 1,350 feet, vertical acceleration and stress were measured at 50- and 10-foot depths.

Records were obtained on 52 out of 64 gage channels installed. Losses were caused by mechanical failure of one oscillograph and by miscellaneous individual channel failures.

Waveforms of acceleration and velocity showed no ideal or classical shape but could be grouped in six categories according to their characteristics.

Outrunning occurred at the ground surface at 2,500-foot ground range from a signal originating at 1,900-foot ground range. However, outrunning can occur at closer ranges for deep measurements, and refracted signals may be recorded after arrival of local effects, as evidenced by acceleration measurements.

Attenuation of maximum downward acceleration at 5- and 10-foot depths varied between 30 and 45 percent except at 550- and 650-foot ranges where it was negligible. At greater depths, wave theory concerning energy transfer at an interface between two materials was borne out. Horizontal (outward) acceleration at 10- and 50-foot depths was attenuated less with depth than was the corresponding peak downward acceleration.

Peak downward velocity followed an exponential decay law rather than a power law decay characteristic of downward acceleration. At 275-psi level, horizontal (outward) velocity showed somewhat less attenuation with depth than the downward component. At the 100-psi level, peak outward velocity at 50-foot depth was twice that at 10-foot depth, owing to signals from sources closer to ground zero.

Attenuation of peak displacement corresponded closely to attenuation of peak velocity.

Attenuation of maximum vertical stress was slight between the surface and 5-foot depth, and stress decreased by half for every 10-foot increase in depth, except at 50-foot depth where it increased. Stress measurements on this project were not considered entirely successful, despite extreme caution exercised in gage placement and backfill procedure.

At 275-psi overpressure, peak strain decreased abruptly between 1- and 30-foot depths, leveling off to a constant value at greater depths. At 100-psi overpressure, vertical strain showed almost no change with depth. This difference between the two stations could probably be traced to the longer rise time of the overpressure at 100 psi than at 275 psi.

The velocity-jump peak overpressure ratio increased with decreasing pressure, with no apparent systematic variation with yield, overpressure level or waveform, or test area. Experimental ratios agreed well with the theoretical result. Peak vertical displacement-overpressure impulse ratio data were too scattered to allow firm conclusions.

From displacement-response spectra, the change in the character of the response appeared to be associated with the interference of the refracted ground-transmitted wave and not with the local ground wave. Normalized velocity spectra for 5-, 10-, and 50-foot depths showed similar maxima although the frequency at which this maximum occurred decreases with increasing depth.

In stress-strain relations, it was tentatively concluded that laboratory triaxial tests were more useful in correlation with blast results than were compaction tests.

A.1.5 Project 1.5. Agency: Sandia Corporation. Report Title: Ground Motion Studies at High Incident Overpressure, WT-1405. Project Officer: William R. Perret.

This project was concerned with free-field motion in soil subjected to airblast loading in peak-overpressure ranges greater than 50 psi and through depths greater than had previously been studied. This study was intended to furnish basic data from Shot Priscilla in terms of both acceleration and displacement versus time for use in protective-construction design. In addition to displacement-time data, observation of permanent displacement on a diameter through ground zero served to indicate the residual compression of the soil. A third part of the study, observations of acceleration in buried vertical reinforced concrete structural elements, was included to provide information that could be correlated with free-field results. Data from this project served also for correlation with pertinent design information derived from related studies of Program 3.

Project 1.5 observed vertical and radial accelerations and vertical displacements produced in the ground by air shock from Shot Priscilla, which had an estimated yield of 36.6 kt, and a burst height of approximately 700 feet. Instrumentation was included to measure vertical acceleration at two depths in the vicinity of ground zero and both radial and vertical acceleration at the surface and at depths of 10, 30, 60, and 100 feet for pressure ranges of 270, 187, 120, and 59 psi. Vertical acceleration was observed at a depth of 200 feet at the 300-psi station. Relative displacements were measured between the surface and points roughly 10, 30, 60, 100, and 200 feet deep at each pressure range. Motion of three reinforced, cast-in-place, concrete piles extending from the surface to a depth of 100 feet, adjacent to the 187- and 120-psi free-field instrument stations, was studied by accelerometers near the top and bottom of each pile. Permanent ground displacement was observed by preshot and postshot first-order surveys of a series of monuments.

Data from the station near ground zero was lost, because of temporary adverse effects of ionizing radiation on cable insulation. Seven additional channels of accelerometer data were lost, because of carrier failure after a zero-time short circuit in one amplifier. A total of 64 of 73 readable records were recovered by Project 1.5.

Ground-baffle air-pressure gages recorded overpressures roughly in the predicted range.

Precision of ground-acceleration data was adversely affected by low ratios of signal to set range. Accelerations were attenuated as the inverse 0.75 power of depth except at the station of highest incident overpressure, where the exponent was 1.4. Peak radial accelerations were generally similar to peak vertical accelerations except at surface gages.

Peak transient vertical displacements decreased exponentially with depth to a point below 100 feet. No definitely measurable transient displacement occurred below 100 feet. At all stations the absolute vertical displacement maxima δ decreased exponentially according to $\delta = \delta_0 e^{-0.017D}$, where D is depth in feet and the zero subscript denotes surface displacement.

A.1.6 Project 1.7. Agency: Air Research and Development Command. Report Title: Loading on Simulated Buried Structures at High Incident Overpressures, WT-1406. Project Officer: E. H. Bultmann.

This project was conducted to study the factors affecting transmission of air-induced ground pressures and loadings produced on buried structures by such pressures.

The field test program involved 68 devices (drums) composed of rigid cylinders with deformable-diaphragm ends. Five diaphragm thicknesses were used to simulate structures of different flexibilities. The drums were buried at depths ranging from 0 to 20 feet at three different locations. The average effective peak surface overpressures from Shot Priscilla, as measured by surface diaphragms and BRL surface pressure-versus-time gages, were 231, 108, and 62 psi, respectively, for the near, intermediate, and far locations.

Static measurements made on the diaphragms before and after the test consisted of strain-gage readings and permanent-deflection measurements. Transient strain measurements also were made on some of the diaphragms. A laboratory program was conducted to calibrate the field test devices.

The results indicated that there was a considerable decrease with depth of the air-induced ground-transmitted pressure, as indicated by pressures on similar diaphragms at different depths. This amounted to 70 percent in 20 feet. Pressures on the thinnest diaphragms were found to be as low as 50 percent of the estimated pressure in the soil surrounding the drum when the drum was at a depth equal to its span. The pressure on vertical diaphragms, i.e., horizontal drums, varied from 0.25 to 0.53 of the pressure on horizontal diaphragms. The simplified theory developed gave reasonable predictions of the measured pressures on the buried drums.

A.1.7 Projects 1.8a and 1.8c. Agencies: Ballistic Research Laboratories and Stanford Research Institute. Report Title: Effects of Rough and Sloping Terrain on Airblast Phenomena, WT-1407. Project Officers: E. J. Bryant, and L. M. Swift.

The primary objective of Project 1.8a was to determine the effect of rolling, steep slopes and rough terrain on nuclear blast wave parameters. The secondary objectives were to provide phenomenological measurements to Project 1.8b for correlation with damage to drag-sensitive targets, and to provide blast wave measurements in support of Project 1.8c.

Five blast lines and a few scattered stations were instrumented with self-recording and electronic gages. The blast lines consisted of a flat terrain line used as the control line for comparison with other lines (Line 1), a rolling terrain line of small hills and dales (Line 2), two ridges with approximately symmetrical front and back slopes (Lines 3 and 4), and a rough mountainous line (Line 5).

The objective of Project 1.8c was to obtain data on the effects of gross variations of terrain upon a blast wave produced by a nuclear explosion, particularly at ground ranges of importance to moderately hard targets. During Shot Smoky (44 kt, 700-foot tower), total head pressure, pitot tube dynamic pressure, and overpressure were measured on both sides of a ridge that rose approximately 280 feet to a crest about 1,600 feet from ground zero (Line 3), and at several equivalent ground ranges along relatively smooth terrain (Line 1) for comparison with Line 3. Lines 1 and 3 were jointly instrumented by Ballistic Research Laboratories (1.8a) and Stanford Research Institute (1.8c).

In general, it can be concluded from the results of Projects 1.8a and 1.8c that the presence of a hill, or terrain rise, that shields the line of sight from a nuclear burst causes higher-than-usual temperatures on the front slope and lower-than-usual temperatures on the back slope. That this was the case was indicated by the higher-than-usual shock front velocities over the front slope, decreasing abruptly over the slope crest, dipping to near-sonic values over the back, and finally increasing somewhat to equal the velocities obtained over the flat terrain.

On the basis of measured maximum surface overpressures, it is concluded that the rolling terrain (Line 2) caused a weaker precursor wave than that over the flat line, evidenced by less severe depression of overpressure. The low ridge (Line 3) showed higher overpressure on the front slope, lower over the crest, and higher on the back slope when compared with the flat line. Results on the higher hill (Line 4) were similar to those on the low hill, but pressures on the former were lower on the back slope than on Line 1. On the mountain region (Line 5), there was little deviation of surface overpressure from Line 1.

The only significant differences between the surface and aboveground overpressures were at the crests of the slopes, where aboveground pressures were higher.

The overpressure positive impulse and duration results from Smoky agree well with those from previous operations. There were no apparent terrain effects evident upon the usual relationships for either positive duration or impulse.

Dynamic pressure measurements confirm the conclusion that the precursor wave was weaker over the rolling terrain (Line 2). The low ridge (Line 3) measurements indicate pressures higher than for Line 1 on the front slope and crest, below Line 1 on the back slope, and equal to Line 1 near the bottom of the back slope. These results confirm the hypothesis that the blast wave in the cleanup region does not remember that it has encountered a gross terrain obstacle and that it quickly resumes the character of a flat line at the same range.

A.1.8 Project 1.8b. Agency: Ballistic Research Laboratories. Report Title: Effects of Rough Terrain on Drag-Sensitive Targets, WT-1408. Project Officer: E. J. Bryant.

The objective of Project 1.8b was to investigate the blast damage sustained by drag-sensitive targets when the blast wave passes over rough, hilly terrain to the target location. Of particular interest was the difference in the damage sustained by those targets which were positioned to take maximum advantage of terrain at corresponding distances.

For this study 51 jeeps were exposed on Shot Smoky. Vehicles were placed on three blast lines: a control line of essentially flat terrain, a line of rolling terrain, and a line of steeply sloping terrain with scattered gullies and washes. Earth revetments were constructed to examine the protection they would provide for vehicles. Project 1.8a made airblast measurements at each station.

After the shot, the damage, orientation, and displacement of the vehicles were recorded. The results showed that the damage sustained by those vehicles on regular terrain agreed with the TM 23-200 damage chart. However, the damage sustained by those vehicles which utilized severe terrain irregularities was greatly reduced. Where any substantial obstacle, natural or artificial, having steep sloping rear walls was interposed between the detonation and the vehicle, damage was reduced from severe or moderate to light.

A.1.9 Project 1.9. Agency: Air Research and Development Command. Report Title: Spectra of Ground Shocks Produced by Nuclear Detonations, WT-1487. Project Officer: J. F. Halsey.

The objective of Project 1.9 was to obtain the displacement velocity and acceleration-shock spectra of ground shocks produced by nuclear devices for use in the design of missile bases and operational equipment when subjected to a similar environment.

The problem of defining design parameters for structures capable of withstanding blast-induced ground shock suggested the use of shock spectra as a suitable means of presenting environmental conditions. Self-contained mechanical reed gages, capable of measuring the displacement shock spectrum over a frequency range of 3 to 300 cps in any one direction, were placed on Shots Stokes, Smoky, Galileo, Whitney, and Charleston. Canisters containing the gages were normally placed with tops flush to the ground level at predicted pressure levels of approximately 100 psi; however, on Shot Smoky two additional gages were placed on the floor of an earth-covered-personnel shelter, and two gages were installed on a concrete block for Shot Whitney.

A composite plot of the results of surface gages from Shots Smoky, Galileo, and Whitney (overpressures from 116 to 146 psi) indicates some very definite trends. The displacements are two to three times higher at three cps for the vertical component (3 inches to 5½ inches) than for the radial component (1 inch to 2 inches). The rate of decrease of displacement with increasing frequency is greater for the vertical component than for the radial component. A comparison of the results from the surface gages and those within the structure on Shot Smoky indicates an attenuation factor of three for vertical displacements, with no appreciable change in the radial direction.

A.2 PROGRAM 2: NUCLEAR RADIATION STUDIES

A.2.1 Project 2.1. Agency: U.S. Army Chemical Warfare Laboratories. Report Title: Soil Activation by Neutrons, WT-1410. Project Officer: Philip W. Krey.

The overall objective of this project was to investigate the induction of gamma-emitting radioisotopes in homogeneous soils by nuclear detonations and the subsequent generation of hazardous radiation levels in the vicinity of the detonations, so that the radiological hazard to personnel in these areas could eventually be predicted.

The specific objectives were: (1) to measure the field dose rates from neutron-induced activity in several American soils; (2) to measure the thermal-neutron flux as a function of depth beneath the surface and distance from ground zero for several American soils; (3) to analyze the gamma spectra of the induced nuclides in the soil as a function of depth beneath the surface of two different American soils; (4) to check these data with theoretical estimations of such effects; and (5) to examine the effect of moisture content in soil activation.

Three test soils were used: Dade fine sandy loam which has a high silicon content and low mineral content; Chester loam which has a strong aluminum concentration and a fairly high manganese content; Nevada Test Site soil which has a large sodium composition, significant aluminum and manganese content, and is the natural terrain over which the detonations at Operation Plumbbob took place. The test soils were exposed during Shot Owens at distances of 200 to 500 yards from ground zero, and core samples of each soil were recovered. Measurements of these core samples permitted estimates of the dose rates that would have been generated if Shot Owens were detonated over infinite fields of these test soils. Gamma-ray spectrometric analyses were also performed as a function of depth in some of the core samples. The monitoring of copper-ribbon neutron detectors which had been placed inside the core samples gave a measure of the thermal- and slow-neutron flux as a function of depth in the soils.

Induced field surveys were made during Shots Franklin, Lassen, Wilson, Priscilla and Owens. The conclusions drawn were:

The technique of exposing relatively small homogeneous soil samples to a nuclear detonation and the subsequent measurement of the induced activity in these samples to estimate the dose rate over an infinite field of the same soil was successful. The estimated field dose rates generated over the soils tested varied from about 1 r/hr to 600 r/hr at H+1 hour according to the type and distance of the soil from ground zero during Shot Owens.

The surface thermal-neutron flux at the project stations for Shot Owens was about 3×10^{13} to 2×10^{14} neutrons/cm^2 while the copper flux at these stations ranged from 5×10^{13} to 6×10^{14} neutrons/cm^2. Both the thermal flux and copper flux then reached maximum values of about 10 to 80 percent higher than the surface flux at depths ranging from 5 to 15 cm below the ground surface, according to the soils tested.

Analysis of the gamma spectra in two of the soils tested showed only Na^{24} and Mn^{56} to be of military significance at times greater than H + 1 hour. Zero time surface activation values of 0.6 to 10 μc of Na^{24} per gram of soil and 13 to 108 μc of Mn^{56} per gram of soil were found in the soil samples exposed at the project stations. The activation of these nuclides with depth generally followed the copper flux and thermal flux with depth.

On the basis of the soils tested and the data obtained, the induced dose rates generated by a nuclear detonation over the soils tested can be predicted by the method of Kaufman within a factor of two-to-three from either copper or thermal-neutron flux calculations. Induced dose rates from soils similar to Nevada and Chester (but not Dade) soils can be predicted by the method of Cowan or Canu and Dolan within a factor of about three.

About 80 to 85 percent of the total activity generated in normal Chester and Nevada soils by Shot Owens is concentrated in the top 30 cm. About 95 percent of the total activity is concentrated in the same depth of the Chester and Nevada 100-percent-moisture-saturated soils. Increased water content in soils increased the dose rates generated over these soils by a nuclear detonation by as much as 70 percent.

The copper-neutron flux as a function of depth in soil is primarily dependent upon the moisture composition of the soil. The copper-neutron flux at the surface, the total number of neutrons absorbed in the soil, and the total activity generated in the soil to a depth of 60 cm are also dependent primarily on the moisture composition of the soil when the chemical composition is otherwise constant.

A foot soldier could incur as much as 135 r at H + 1 hour if he traversed at 3 mph a patch 1,800 yards long over Nevada or Chester soil, where the midpoint of the path was the ground zero of a weapon with detonation conditions similar to the Owens device. If the same action were taken at H + 10 hours, a dose of not more than about 30 r would be accumulated. A serious radiological hazard does not exist to unprotected personnel passing through the ground zero over Dade soil.

If an armored personnel carrier were driven at 5 mph through ground zero of a weapon similar to the Owens device detonated at 500 feet over Nevada or Chester soil, a total dose of no more than 35 r would be accumulated at H + 1 hour, as compared to a total of 7 r at H + 10 hours.

A.2.2 Project 2.2. Agency: U. S. Naval Radiological Defense Laboratory. Report Title: Neutron-Induced Activities in Soil Elements, WT-1411. Project Officer: C.S. Cook.

Neutrons which escape following the detonation of a nuclear device interact with matter within range of the neutron flux. Some of these interactions produce radioactive isotopes. It was the purpose of this project to study the nature of this radioactivity, especially the problems associated with induced radioactivity in soils near ground zero.

During Shots Wilson, Owens, and Laplace, samples of elements most common in the various soils of the world were placed in locations between 100 and 1,000 yards from ground zero and at depths down to 24 inches below the surface. Also, gold and sulfur neutron detectors were placed with these samples to measure the neutron fluxes.

A NaI(Tl) crystal gamma-ray spectrometer with a 100-channel pulse height analyzer was used to measure the radiation from selected small elemental samples. From the data obtained, the specific activity of each type of elemental sample has been determined. Although certain other elements which are in large abundance in selected soils may require consideration of a radioactive isotope of that element, it appears that generally, the most significant radioactive isotopes produced in soils are Na^{24}, Al^{28}, and Mn^{56}.

The relative intensities of thermal and fast neutrons as a function of soil depth are different. Thermal neutron intensities increase to a maximum a few inches below the surface. Fast neutron fluxes (sulfur detector neutrons) decrease rapidly with depth. Most induced activity appears to be the result of thermal (n, γ) reactions, although for a few elements it can be seen that the fast neutron (n, p and n, α) reactions may contribute measurable quantities of radioactivity.

It appears that very few neutrons reach the soil directly from the device. Most neutrons which are effective in producing radioactivity have been scattered at least once in the air. Thus, the neutrons diffuse into the earth as a function of vertical depth, and not as a function of slant range from the point of detonation of the device.

For selected soils these neutrons may produce, near ground zero, gamma-radiation fields at the time of detonation as great as several thousand r/hr. It is the exceptional soil that produces a gamma-ray field the order of magnitude of which is less than 100 r/hr at time of detonation (for the conditions of detonation of Shots Wilson, Owens, or Laplace).

Gamma radiation from radioactivity induced in an M-48 tank at Shot Hood was observed to be entirely Mn^{56} radiation.

A.2.3 Project 2.3. Agency: U. S. Army Chemical Warfare Laboratories. Report Title: Neutron Flux from Selected Nuclear Devices, WT-1412. Project Officer: David L. Rigotti.

The objectives of this project were to measure the neutron flux and spectra for certain selected devices being tested during Operation Plumbbob and to provide neutron flux, spectra, and dose measurements in support of other projects. A total of approximately 1,500 neutron flux measurements were made utilizing the following detector elements: gold, plutonium, neptunium, uranium, sulfur;

For Shots Franklin, Wilson, Laplace, and Owens the measured dose values exceeded the predicted values obtained by use of the neutron dose curves of TM 23-200 by factors of 2.4, 2.9, 3.0, and 5.6 respectively. For Shot Priscilla, the measured dose was lower than the predicted dose by a factor of 1.2.

Beyond 300 yards from ground zero there was no variation with increasing distance of the neutron energy spectrum above the thermal energies.

The extrapolation of the straight-line portion of the curve of neutron flux times slant distance squared versus the slant distance to close-in distances was invalid, since experimental data from Operation Plumbbob confirmed that the relationship was nonlinear at close ranges.

The foil-detector system for measuring neutron flux gave reproducible results, further verifying its suitability for use in making measurements in nuclear weapons tests.

A.2.4 Project 2.4. Agency: U. S. Army Chemical Warfare Laboratories. Report Title: Neutron and Initial-Gamma Shielding, WT 1413. Project Officer: Robert C. Tompkins.

The objectives were to: (1) perform neutron- and gamma-shielding tests on structures, shelters, fortifications, Ontos vehicles, and M-48 tanks to fill in the gaps in existing empirical data; (2) determine relative neutron and gamma inside/outside dose ratios for two types of tank armor, which the Ordnance Corps will attempt to correlate with contemplated laboratory shielding studies; and (3) perform neutron- and gamma-attenuation studies in soil in order to obtain an indication of the variation of gamma dose, neutron dose, and neutron spectrum with depth.

Instrumentation for neutron shielding consisted of gold flux detectors; plutonium, neptunium, and uranium fission-threshold detectors; sulfur-threshold detectors; and chemical dosimeters. Instrumentation for gamma shielding consisted of photographic and chemical dosimeters. The shielding characteristics of M-48 tanks, Ontos vehicles, and hemispheres of standard and plastic laminated tank armor were studied during Shots Franklin, Lassen, Wilson, and Hood. The attenuation of neutrons and gamma rays by prepared Nevada Test Site (NTS) soil was investigated during Shot Owens. Field fortifications and underground shelters were instrumented for Shot Priscilla.

The neutron inside/outside dose ratio in the M-48 tank varied from 0.28 to 0.59, depending upon crew position and orientation. The gamma inside/outside dose ratio in the M-48 tank varied from 0.11 to 0.67, depending upon crew position, orientation, shot, and measurement technique. The neutron inside/outside dose ratio for the Ontos vehicle was about 0.58, while the gamma ratio varied from 0.33 to 0.88, depending upon orientation, shot, and measurement technique. Because a large part of the initial gamma dose was due to radiative capture of neutrons in the armor, gamma inside/outside dose ratios are unsuitable for hazard assessment in an armored vehicle. The commander's position in the M-48 tank is most vulnerable to both neutrons and initial gamma. An M-48 tank crew can be killed by initial, nuclear radiation from a tactical nuclear weapon at ranges where the tank sustains no blast damage. The only observable residual activity induced in tank armor was 2.58 h Mn^{56} ($t\frac{1}{2}$ = 2.58 hours); the dose delivered to the crew by residual radiation was insignificant compared to the initial radiation.

The plastic-laminated armor apparently reduced the measured neutron dose twice as effectively as the standard armor, but the spectral data suggests that all the neutron dose may not have been measured. On the other hand, the initial gamma radiation was the same in both types of tank armor.

The thermal-neutron flux in dry NTS soil increases with depth to about 15 cm and then decreases. During Shot Owens, the fast-neutron spectrum hardened with depth in dry NTS soil. The attenuation of neutron dose by this soil was predicted from reactor-shielding data with good accuracy only at 260 yards slant range. Useful gamma-attenuation data was not obtained in the soil because of activation of detectors, capture-gamma radiation, and soil activation by the high neutron flux.

The modified, two-man foxhole gives no better radiation protection than the standard, two-man foxhole with one-third cover. The offset foxhole provided good radiation protection with either entrance design. Shielding by a field fortification cannot be predicted with confidence at this time.

The buried concrete arches of Project 3.1 provided inadequate radiation protection but would be satisfactory with improved entranceway design. The buried conduits and cattle passes of Project 3.2 provided very satisfactory radiation protection. The buried steel arches of Project 3.3 provided good radiation protection, which could be improved by minor modification of the entranceway.

Any shelter buried under at least 4 feet of earth will provide adequate protection from initial nuclear radiation when the external dose is not greater than 10^7 rep.

A.2.5 Project 2.5. Agency: U.S. Army Signal Research and Development Laboratory. Report Title: Initial-Gamma Radiation Intensity and Neutron-Induced Gamma Radiation of NTS Soil, WT-1414, Project Officer: G. Carp.

Part 1. The objective of the first part of this project was to determine initial-gamma intensity versus time and distance, both on the ground and in the air. Measurements were made during the period from 1 msec until 20 seconds after time zero for six shots. Ionization-chamber detectors covered a range from 10^{-3} to 10^{-4} r/sec. Detectors were located at the surface of the earth, on balloons 950 feet above the surface, in aircraft, and in armored tanks.

A limiting factor in determining delivery procedure for air-to-air weapons is the initial-gamma and prompt-neutron radiation received by the pilot of the delivery aircraft. The three aircraft that participated during Shot John were instrumented to make such gamma measurements. Inasmuch as only a limited amount of data could be obtained during Shot John, this project supported Project 2.10 by making measurements from balloons on four shots.

Seven surface stations were located at 500-yard intervals from ground zero. The basic measurements were made by use of saturated ion-chamber detectors whose outputs were recorded by magnetic-tape recorders. Backup measurements were made with a mechanical device that used photographic dosimeters on a moving belt.

Initial-gamma dose rates and total integrated doses from 33 electronic installations and 18 photographic-dosimeter installations are presented. The data shows initial-gamma radiation arising from the capture of neutrons in atmospheric nitrogen (n, γ radiation) and from fission-product decay. The (n, γ) radiation accounted for almost all of the gamma radiation delivered between a few milliseconds and 0.25 second, and represented 60 to 85 percent of the total dose.

The effect of the rising fireball caused gamma rates to decrease rapidly after about 5 seconds, particularly at the close-in stations. The hydrodynamic effect caused an observable increase in gamma intensity during Shot Hood.

Results of measurements of the air-earth interface from four sets of balloon and ground data show that gamma rates 950 feet above the ground average 32 percent higher than on the ground.

Fifty percent of the total exposure was received by the delivery aircraft for Shot John during a second maximum of gamma intensity corresponding to the closest approach of the aircraft to the fireball.

The total gamma dose and dose-rate measurements at 500 and 1,000 yards greatly exceeded values given in TM 23-200. The dose-rate data and total-dose data are generally accurate to within ±20 percent. The accuracy of the data presented warrants its use in further analysis of dose-rate phenomena.

Part 2. The objective of the second part of this project, in support of Project 2.1, was to measure neutron-induced gamma rate as a function of time at four stations during Shot Owens for an infinite plane of Nevada Test Site (NTS) soil.

The neutron-induced gamma radiation was detected by a saturated ion-chamber detector whose output determined the frequency of pulses recorded on an electromechanical recorder. The instrumentation was designed to make the required gamma measurements without perturbing the measured field. In order to eliminate induced activity in the instrumentation, the complete station was buried 3 feet beneath the surface. The detector was raised above the ground after the decay of the neutron radiation.

Although three of the four installations failed because of minor mechanical defects, the instrumentation system is deemed satisfactory for neutron-induced activity measurements at NTS. The 500-yard station during Shot Owens detected a dose rate of 55 r/hr at H+1 hour, as compared with a dose rate of 43 r/hr obtained by Project 2.1.

A.2.6 Project 2.6. Agency: U.S. Army Signal Research and Development Laboratory. Report Title: Evaluation of New Types of Radiac Instruments, WT-1415. Project Officer: A.E. Cohen.

The objectives of this project were to evaluate the response of newly developed gamma-neutron dosimeters and the field operational adequacy of a new beta-gamma ion-chamber rate meter.

In the evaluation of the neutron-dosimeter system, tissue-equivalent tactical neutron dosimeters, as well as standard radiac meters (IM-93), were exposed to initial nuclear radiations from Shots Wilson, Priscilla, and Hood. The readings were compared to those made with the Sigoloff chemical dosimeters and with the National Bureau of Standards (Evans) film dosimeter.

In the evaluation of the IM-123 (beta-and-gamma) radiac meter, 24 instruments were procured. The instruments were employed by Rad-Safe teams in actual radiological fields resulting from Shot Hood. The teams were questioned on the operational performance of the instruments. The results of this questionnaire were tabulated. The instrument indications were compared in the field against those of the now-employed AN/PDR-39 and a good gross correlation under field conditions appeared in the gamma indications. For determination of the soft-component-measuring capability of the instrument, comparison was made with a specially designed beta-gamma meter (Model 1002).

The results of the neutron-dosimeter-system evaluation, although preliminary in nature, indicated that the system tested did not measure neutron dose satisfactorily. The results further indicated that none of the ion-chamber dosimeter instruments measured gamma dose accurately under conditions of high neutron flux, although they did so when there was only a small amount of neutron radiation present.

The results of the IM-123 evaluation were impaired by lack of sufficient beta data. The instrument seemed to possess promising features, but further development will be necessary to make it reliable for Army field use.

It is concluded that the neutron-dosimeter system tested was subject to some effect, probably a neutron dose rate dependency, which caused the loss of accuracy. The recommendation is made for more laboratory study of this effect and the dosimeter system.

A.2.7 Project 2.7. Agency: U.S. Naval Research Laboratory. Report Title: Investigation of Effects of Nuclear Detonations on Electromagnetic Wave Propagation and Nuclear Radiation Detector Design, WT-1416. Project Officer: T.D. Hanscome.

The objectives of this project were to: (1) proof-test (at Nevada altitudes) telemetry and nuclear radiation detection techniques intended for use in measurements of effects of high altitude nuclear detonations; (2) study radio wave propagation in the vicinity of nuclear detonations; (3) study the effects of the electromagnetic signal produced by the detonation on the equipment used; and calculated and measured attenuations were compared.

Transmitters in the frequency range 160 to 9,850 Mc were located (a) in shielded bunkers to transmit radially outward from ground zero, (b) such that the transmission path went through the fireball, and (c) such that the signal reflected from the fireball could be received. Receivers were installed in Building 400, about 12 miles from the various ground zeros. Scintillation detectors were installed at some of the stations closer to ground zero, as were instruments to monitor the effects (on the transmitters) of the electromagnetic signal generated by the detonation.

For frequencies near 10,000 Mc, radial path attenuations greater than 50 db, but probably less than 75 db and lasting about 5 microseconds were observed for transmitters at about 1,300 yards from a 10.3-kt device (Wilson). For a radial path and a 71-kt device (Hood), the attenuations were greater than 75 db and lasted about 15 μsec for a transmitter at 1,600 yards from ground zero. In both of these measurements, the signal strength recovered to its preshot value in less than about 30 microseconds.

Transmission at 160, 960 and 9,750 Mc through the fireball was interrupted as long as the fireball intersected the path between transmitter and receiver, but was restored as soon as the fireball moved out of the direct path. Extensive diffraction and multiple path phenomena were observed.

An upper limit of .09 was established for the reflection coefficient of the Priscilla fireball at 9,750 Mc.

Gamma-ray measurements were obtained at 1,600 yards from Hood and Owens. The detectors performed satisfactorily, and were not affected by the electromagnetic signal from the detonation.

Serious effects due to the electromagnetic signal from the detonation were noted in a bunker 1,270 yards from Hood, and in the receiving station, about 15 miles from ground zero. The effects in the bunker were apparently due to penetration of the copper shield by the electromagnetic signal, and in the receiving station to the large voltage excursions induced on the power line system.

The maximum intensities of the components of the Diablo electromagnetic signal that fell in the pass bands of the receivers were found to be (a) 25 microvolts per meter at 160 Mc, (b) 40 microvolts per meter at 960 Mc, and (c) no signal was observed at 9,850 Mc (minimum detectable signal was 50 μv/m). The peak intensities of the Kepler and Owens electromagnetic signals at Building 400 were found to be −10 volts/meter and −45 volts/meter respectively.

A Monte Carlo calculation of the electron energy distribution has been made, and preliminary results of this calculation used, with the measured gamma-rays, to calculate the radio wave attenuation. The calculated and measured values do not agree over the entire time of attenuation. It is apparent that there are other factors which must be taken into account before a satisfactory calculation of the expected attenuation can be made.

A.2.8 Project 2.8. Agency: Naval Material Laboratory. Report Title: Evaluation of Military Radiac, WT-1417. Project Officer: E.J. DiIanni.

Objectives of Project 2.8 were to (1) develop suitable shields for Navy dosimeter types IM-107/PD (quartz fiber) and DT-60/PD (silver phosphate glass) in order to correct their response to agree with that of standard depth dose detectors imbedded 4 cm in masonite phantoms and (2) compare externally held ratemeter readings with that of a dose-rate standard also imbedded 4 cm in masonite phantoms.

Based on laboratory gamma shielding studies conducted in the range 80 kev to 1.25 Mev, external shields were developed for use with the above dosimeters. The masonite phantoms were designed to simulate average human torso configurations. The effectiveness of the shields in actual field radiological situations was determined in the distributed fields resulting from the induced radiation from Shots Wilson, Priscilla, and Hood and the fallout field from Shot Diablo.

Studies were made of the correlation between dose rates as measured by the AN/PDR-43 (XN-1) and the AN/PDR-44(XN-1) and the dose rates indicated by the Naval Material Laboratory standard depth-dose ratemeter.

The results of the measurements performed indicate that the laboratory shields provided for the IM-107/PD are adequate to provide good correlation with depth dose. Additional shielding is required for the DT-60/PD. Shielding is needed for the AN/PDR-43 and the AN/PDR-44. Results were similar for both neutron-induced and fallout fields.

A.2.9 Project 2.9. Agency: Air Force Special Weapons Center. Report Title: Nuclear Radiation Received by Aircrews Firing the MB-1 Rocket, WT-1418. Project Officer: Kermit C. Kaericher.

Three F-89 all-weather interceptor aircraft participated in the successful delivery (Shot John) of a live MB-1 air-to-air rocket on 19 July 1957 at the Nevada Test Site. The rocket was launched to detonate at a predetermined point at 19,000 feet MSL. All crew members and aircraft were instrumented to measure total neutron and gamma radiation.

Neutron instrumentation in each aircraft consisted of fission foils, gold and sulfur threshold detectors and chemical dosimeters. Two of the three crews were processed through the Los Alamos Scientific Laboratory human counter. The most refined neutron dosimetry data resulted from the whole body counter with only an upper limit check indicated by the threshold detectors.

Gamma radiation was measured by chemical dosimeters and by National Bureau of Standards and Rad-Safe film badges. In addition, gamma dose rates were measured by an initial-gamma-versus-time recorder installed in the aircraft and are reported separately in WT-1414.

Neutron and gamma radiation dosages received by the crew members were less than had been predicted. To some extent this may be attributed to the effect of aircraft shielding, which was not utilized in the theoretical predictions. No crew member received more than 5 rep neutron and 3 r gamma during his participation.

The experiment proved that the MB-1 air-to-air rocket can be successfully launched by the F-89 aircraft at 19,000 feet MSL with a radiation dose to the delivery crew within acceptable limits.

It is considered that radiation dosage extrapolations to both higher and lower operational altitudes are reliable to within a factor of two.

A.2.10 Project 2.10. Agency: Air Force Special Weapons Center. Report Title: Initial Neutron and Gamma Air-Earth Interface Measurements, WT-1419. Project Officer: E.N. York.

Measurements of total gamma dose, gamma dose rate, neutron flux, and neutron dose were made at the surface and at heights up to 950 feet to determine the effect of the air-ground interface on initial nuclear radiation. Measurements of total gamma dose and neutron flux were made with dosimeters fastened to towers 500 feet high and to the mooring cables of captive balloons 950 feet high. Total gamma measurements were made with three types of film badges, two types of phosphate glass dosimeters, quartz-fiber dosimeters, and chemical dosimeters. Neutron-flux measurements were made with sulfur pellets and with nuclear track emulsions. Neutron-dose measurements were made with chemical dosimeters. Measurements of gamma dose rate were made with air-filled, saturated, ion-chamber detectors carried by captive balloons with signals carried by miniature coaxial cable to ground stations and recorded on magnetic tape.

It was found that total gamma dose increased with height to a value, at 400 feet, 30 percent greater than ground measurements. There was no further increase up to 950 feet. The effect was the same at all stations from 1,500 to 3,500 yards horizontal distance from burst point. There was no change in the ratio of gamma dose rates at the balloon stations compared to dose rates at ground stations over the first 5-second interval for which records were obtained.

Sulfur neutron-flux measurements increased with height to a value of 30 percent greater than ground measurements at 500 feet. No change was observed from 500 feet to 950 feet. Neutron rep-dose measurements were not conclusive.

A.2.11 Program 2. Agency: Headquarters, Field Command, Sandia Base. Report Title: Neutron and Gamma Radiation from Shot Laplace, WT-1541. Project Officer: John A. Chiment[redacted]

The objectives of this experiment were to determine for Shot Laplace, a 1.22-kt [redacted] device fired late in Operation Plumbbob: (1) intensity and decay of the neutron-induced gamma field; (2) neutron flux and spectra as a function of distance; (3) neutron flux as a function of soil depth with certain selected detectors; and (4) neutron dose and initial gamma dose as a function of distance.

The documentation of the induced field intensity and its decay was accomplished through use of two types of gamma survey meters, the AN/PDR-T1B and the Jordan Model AGB-10SR. Neutron flux and spectra were measured by the threshold-detector technique, employing gold, cadmium-shielded gold, plutonium, neptunium, uranium, and sulfur for ground-surface measurements, and gold, cadmium-shielded gold, and sulfur for soil-depth measurements. Various types of film-badge and chemical dosimeters were used to measure the initial gamma dose, while neutron dose was determined by calculation from the flux-spectra results.

The neutron-induced gamma radiation field and its decay from H + 1 to H + 36 hours was successfully documented. The observed decay rate indicated Na^{24} and Mn^{56} as being the major contributing radionuclides during the time covered by the observations. A survey of the neutron-induced field at H + 27 hours indicated dose-rate levels ranging from 2.6 r/hr at a slant range of 320 yards to 1.38 mr/hr at 2,015 yards. When extrapolated back to H + 1 hour, the 320-yard reading was found to be equivalent to 16.4 r/hr.

The data obtained in the documentation of thermal (gold) and fast (sulfur) neutron fluxes with soil depth confirmed earlier observations that thermal flux peaks at a depth of approximately 4 inches, whereas the high-energy flux degrades rapidly with depth.

Neutron irradiation of elemental samples of sodium, chromium, and manganese produced the induced activities of Na^{24}, Cr^{51}, and Mn^{56}. The specific activation was reasonably well related to the cross sections of the reactions involved.

The measured neutron dose exceeded that predicted by TM 23-200 by an average factor of 2.6 for ranges between 300 and 700 yards.

The initial gamma dose data showed that Laplace produced a greater-than-predicted gamma dose at all ranges, with the greatest discrepancy occurring at the close-in ranges. The effective mean free path of the initial gamma radiation at ranges in excess of 1,500 yards was 440 yards, slightly greater than the value predicted (using a relative air density of 0.8) of 425 yards.

A.3 PROGRAM 3: EFFECTS ON STRUCTURES

A.3.1 Project 3.1. Agency: U.S. Army Engineer Waterways Experiment Station and U. S. Naval Civil Engineering Laboratory. Report Title: Blast Loading and Response of Underground Concrete-Arch Protective Structures, WT—1420. Project Officer: W. J. Flathau.

The purpose of this project was to evaluate the effects of a kiloton-range nuclear airburst on buried reinforced-concrete arch structures located in the high overpressure region. Since these were to be considered as personnel protective structures, they were evaluated for their resistance to blast, radiation, and missile hazards.

Four structures, with the top of the arch crown 4 feet below ground surface, were positioned at three different overpressure ranges for the Priscilla Shot, a 36.6 kt, 700-foot-high burst. All four arches were semicircular in cross-section, with an inside span of 16 feet and an arch thickness of 8 inches. Three of the structures were 20 feet long and the fourth was 32 feet long. A 20-foot-long structure was placed at each of the predicted ground-surface air overpressure levels of 50-, 100-, and 200-psi, while the 32-foot-long structure was placed at the predicted ground-surface air overpressure level of 50 psi. It was specified that all structures be designed to withstand a 50-psi peak blast overpressure using 3,000-psi concrete. The four structures were instrumented for measurements of air overpressures, earth pressures, deflections, accelerations, strains, radiation, and missiles.

The four structures received actual air overpressures of 56, 124, and 199 psi and suffered only minor damage, all remaining structurally serviceable. The structure at the 199-psi pressure level exhibited obvious cracking of the floor slab and minor tension cracking of the arch intrados; however, even though the damage was slight, the peak floor slab acceleration of 13.4 g may have been physiologically hazardous to personnel.

It was observed that the earth loading around the arch surface was not uniform and that the arch itself underwent appreciable bending. The passive pressure exerted by the soil on the arch surface aided in developing the transmission of the compressive load.

Subsequent analysis, allowing for the actual concrete strength of 4,500 psi, showed that the capacity of the structures at the time of the Priscilla Shot exceeded the specified design capacity of 50-psi ground-surface air overpressure. Consequently, the data obtained are not sufficient for more than tentative conclusions about the ultimate capacity of the structure. A retest at higher overpressures should furnish the additional data needed.

The entranceway of the shelter was designed to exclude air overpressure only, therefore considerable radiation was admitted; however, the entranceway could easily be modified to greatly reduce the amount of radiation transmitted through it to the interior of the structure. Also, the entrance is of the emergency type, for economy, and would be secondary to a rapid access entrance in an actual protective shelter. There were no missile and apparently no dust hazards in any of the structures.

This test showed that an underground reinforced-concrete arch is an excellent structural shape for resisting the effects of a kiloton-range nuclear air burst.

A.3.2 Project 3.2. Agency: Bureau of Yards and Docks and U.S. Naval Civil Engineering Laboratory. Report Title: Evaluation of Buried Conduits as Personnel Shelters, WT-1421. Project Officer: G.H. Albright.

Twelve large-diameter buried conduit sections of various shapes were tested in the 60-to-149-psi overpressure region of Shot Priscilla to make an empirical determination of the degree of personnel protection afforded by commercially available steel and concrete conduits at depths of burial of 5, 7.5, and 10 feet below grade. Essentially, it was desired to assure that Department of Defense Class I (100-psi and comparable radiations) and Class II (50-psi and comparable radiations) protection is afforded by use of such conduits of various configurations.

Measurements were made of free-field overpressure at the ground surface above the structure; pressure inside the structures; acceleration of each structure; deflection of each structure; dust inside each structure; fragmentary missiles inside the concrete structures; and gamma and neutron radiation dose inside each structure.

All buried conduit sections tested provided adequate Class I protection (100-psi overpressure and comparable radiation protection) for the conditions under which the conduits were tested. Standard 8-foot concrete sewer pipe withstood 126-psi overpressure without significant damage (minor tension cracks observed); standard 10-gage corrugated-steel 8-foot circular conduit sections withstood 126-psi overpressure without significant damage; and standard 10-gage corrugated-steel cattle-pass conduits withstood 149-psi overpressure without significant damage. Durations of positive pressure were from 206 to 333 milliseconds.

A.3.3 Project 3.3. Agency: Bureau of Yards and Docks and U. S. Naval Civil Engineering Laboratory. Report Title: Evaluation of Buried Corrugated-Steel Arch Structures and Associated Components, WT-1422. Project Officer: G. H. Albright.

Three underground corrugated-steel arch structures covered with 5 feet of earth were subjected to peak overpressures of 60 and 100 psi during Shot Priscilla at the Nevada Test Site. Essentially, it was desired to assure that Department of Defense Class II (50-psi overpressure and comparable radiations) protection is afforded by two types of 25-foot diameter, 180-degree corrugated-metal arches.

Free-field overpressure was measured at the ground surface above the structures, along with pressure inside each structure, acceleration of the floor slab, arch deflection relative to the floor slab, and gamma and neutron radiation dose inside each structure. Dust was measured inside one structure.

All arch structures provided adequate Class II protection for the conditions of the test. One arch structure, reinforced with steel arch ribs, withstood 100-psi overpressure (333-msec positive-phase duration) with no significant damage other than a cracked floor slab.

A blast closure valve was tested in the ventilating system of one structure. Operation was satisfactory during the positive-pressure phase, but the valve leaked excessively during the negative-pressure phase.

Prototype pits designed to partially shield emergency power generator sets against blast, missiles, and thermal radiation damage were tested to determine their adequacy. Damage assessment indicated significant but inadequate protection at the overpressures to which the generator sets were exposed.

A.3.4 Project 3.4. Agency: Armour Research Foundation, Chicago, Illinois, and Air Force Special Weapons Center. Report Title: Blast Effects on Existing Upshot-Knothole and Teapot Structures, WT-1423. Project Officer: E. H. Bultmann, Jr.

Project 3.4 comprised eight individual tests, seven of which utilized structures remaining from Operations Upshot-Knothole and Teapot. The general objective of the project was to secure blast loading and response data from the behavior of these structures during Operation Plumbbob. In most instances the specific objectives were those of the original test effort. In some cases, however, existing structures were used for new purposes.

The following structures were retested:

1. TP 3.7a-1 and b-1 (full-scale mill buildings)

2. TP 3.8a-1 (reinforced concrete panels)
3. UK 3.8 (underground beams, also tested as TP 3.4)
4. UK 3.7 (underground chamber, modified)
5. UK 3.5ba and bc (roof panel structure, modified)
6. UK 3.29c-1 and c-15 (wall panel structure, modified)
7. In addition to the above, observations were made of a number of existing structures in Frenchman Flat and Area 1 of Yucca Flat for which additional damage was anticipated and which were not included in the test plans of other agencies.

The only completely new items tested were a series of concrete panels whose behavior to close-in thermal radiation was investigated.

The objective of the test utilizing the TP 3.7a-1 and b-1 structures was to determine the blast response of full-scale mill type buildings as a check on the reliability of existing damage prediction schemes, thereby supplementing the results of the original TP 3.7 test. Both the structures collapsed in this test, in accordance with the blast response prediction.

The objective of the test utilizing the TP 3.8a-1 panels was to determine the blast response of fixed-end concrete panels to supplement the findings of the original TP 3.8 test. The panels sustained a slight further permanent deformation.

The objective of the test utilizing the UK 3.8 underground beams was to determine the blast response of these items to supplement the findings of the original test with respect to effective vertical earth pressures and attenuation with depth. The beams sustained appreciable additional deformation in this test. The results obtained showed a marked attenuation of effective vertical earth pressures (i.e., damage) with depth.

The objectives of the test utilizing the modified UK 3.7 structure were to determine the air blast loading in the interior of an underground chamber which is vented to the outside by a relatively large opening, and to determine the response of an underground reinforced-concrete roof slab for the purpose of correlating any damage incurred with existing load and response prediction schemes. The pressure measurements obtained in this structure showed the general precursor shape of the exterior wave and a reduction to 60 percent of the peak overpressure.

The objective of the test utilizing the modified UK 3.5b structure was to determine the air blast loading on a rectangular block in the interior of a partially open building. The data obtained was to be correlated with existing shock tube data on a geometrically similar configuration. The pressure measurements obtained in the empty cell and on the block showed general agreement with shock tube data. The measured peak interior pressures were in excess of the exterior peak pressure by 20 percent.

The test utilizing the modified UK 3.29c test cells was to determine the air blast loading behind solid wall panels (corrugated asbestos and unreinforced cinder block) which fail due to the incident shock wave, and to compare this information with existing shock tube data for model wall panels. The pressure measurements obtained showed that the interior pressure wave was essentially unaltered by the failing corrugated asbestos wall, but that it was markedly affected by the failing cinder block wall. In the latter case the interior wave was a compression wave with a rise time of about 93 msec and a peak overpressure nearly 20 percent in excess of freestream.

The objective of the test utilizing the special concrete panels was to determine the comparative behavior of these materials to close-in thermal radiation. Essentially no damage was observed to any of the panels tested. It is concluded from this that even untreated portland-cement concretes can successfully withstand the effects of thermal inputs comparable to that obtained at 700-foot slant range from Shot Priscilla.

The objective of the test utilizing the various existing structures in Frenchman Flat and Area 1 of Yucca Flat was to gain bonus information on the blast response of these structures and also to maintain a permanent record of the existing condition of structures in this area. Numerous structures sustained additional damage.

<u>A.3.5 Project 3.5a.</u> Agency: Stanford Research Institute. Report Title: Isolation of Structures from Ground Shock, WT-1424-1. Project Officer: R. B. Vaile, Jr.

The effectiveness of frangible backfill (glass bottles) in protecting underground structures from the violent motions produced by nearby explosions was investigated. Two test structures and one comparison structure were used. Each test structure was a reinforced concrete pipe enclosing a steel cylinder separated from the pipe by rubber O-rings, with glass bottles placed around the sides and bottom of the pipe. The comparison structure was a concrete pipe with solid concrete bottom. All three structures were buried with their axes vertical, and their tops approximately 2 feet below ground level. A concrete slab 1 foot thick was set above each, flush with the ground surface. One test structure and the comparison structure were 750 feet from ground zero (229-psi peak overpressure). The remaining test structure was 1,050 feet from ground zero (104-psi peak overpressure).

The peak accelerations of these structures, produced by shear forces exerted against their sides, were reduced by the frangible backfill to 26 percent or less of those that structures in intimate contact with the soil would have experienced.

Four years after the shot the structures were excavated. All the bottles around the sides of the test structure at 229 psi were completely crushed; only a fourth of the bottles at the 104-psi location were broken, most of these on the upper half of the structure.

At the 229-psi location the soil apparently was stressed beyond failure, and the protective capabilities of the backfill were fully utilized. At the 104-psi location the backfill capabilities were 10 percent expended; the configuration could have accepted a second attack at 200 psi or four or five attacks at 100 psi.

The soil beneath the two test structures moved down a greater distance than the structures, and the frangible elements beneath them showed no crushing and only minor fracturing.

The frangible backfill was shown to enhance the protection afforded by an underground structure against more than one attack of relatively small magnitude while retaining a major part of the capability to protect against a single large attack. Further investigation is recommended.

A.3.6 Project 3.6. Agency: Air Force Special Weapons Center. Report Title: Full-Scale Field Tests of Dome and Arch Structures, WT-1425. Project Officer: E.H. Bultmann, Jr.

This report describes tests on dome and arch structures sponsored by the Air Force Project 3.6 and the Office of Civil and Defense Mobilization (OCDM) Project 30.1 during Operation Plumbbob. The primary objectives of the test were to determine the blast-wave loading on dome and arch structures, determine the response motions of domes subjected to blast-wave forces, and check the performance of a large blast door after being subjected to blast-wave forces.

A total of ten structures were used: three 50-foot-diameter, reinforced-concrete, 6-inch-thick, responding domes; two 50-foot-diameter, reinforced-concrete, 24-inch-thick, nonresponding domes; two 20-foot-diameter, responding aluminum domes; two 35-foot-span, 90-foot-long, reinforced-concrete nonresponding arches; and one 7-by-10-foot drawbridge-type door. The nonresponding structures were instrumented to determine pressure as a function of time, and the responding structures were instrumented to determine pressure and displacement as a function of time. A limited number of shear, strain, and ground acceleration measurements also were recorded on the responding domes.

The three 50-foot responding domes were identical as far as was practical to build them. They were placed in the 70-, 35-, and 20-psi regions and were designed to suffer slight damage at the 35-psi level. The aluminum domes were both placed in the 70-psi region. The shell of one was 1 inch thick, the other, $\frac{1}{2}$ inch thick. The nonresponding domes and arches were placed, one each, in the expected 70- and 35-psi regions. The nonresponding domes were self-supporting, while the nonresponding arches consisted of a 1-foot-thick slab poured on an earth mound. The drawbridge door was placed in the expected 35-psi region.

Actual overpressures developed in the predicted 70- and 20-psi regions were very close to the predicted overpressures. The actual overpressure at the expected 35-psi region was about 40 psi.

The responding reinforced-concrete dome in the high-pressure region suffered nearly total destruction. The windward side of the dome in the medium-pressure region was demolished. The responding dome in the low-pressure region was not damaged. No damage was suffered by any of the foundations.

Both aluminum domes suffered total destruction. The $\frac{1}{2}$-inch-thick shell was dished down into the foundation; the 1-inch-thick shell was crushed against the side of the foundation away from ground zero. No damage was suffered by the foundations for the aluminum domes.

The nonresponding domes and their foundations were not damaged by the blast.

The nonresponding arches suffered shear failure along the end walls and a slight displacement, about $2\frac{1}{4}$ inches, for the 70-psi arch, and 1 inch for the 35-psi arch. A tension crack appeared just beyond the crown of the 70-psi arch, the crack running the full length of the shell.

The test of the prototype door was also a success. It survived without significant permanent deformation. The only damage (around the edge of the door) was of minor nature and could be prevented by a slight change in design. The locking and hinge mechanisms functioned perfectly after the test.

Analysis of the loading data failed to disclose any reflected-pressure effects on the structures because of the lack of a classical type of shock front in the precursor blast wave at each of the structures. Enough loading information was obtained on the nonresponding structures at the 70-psi region to permit the computation of pressure coefficients as a function of time on these structures.

The dome-response measurements obtained on the tests generally confirmed the theory which was used for the design of the domes. Failure of certain response gages during the test, notably the strain gages, prevents a complete description of the manner in which the dome structures resisted the blast loading.

A.3.7 Project 3.7. Agency: Ballistic Research Laboratories. Report Title: Instrumentation of Structures for Air-Blast and Ground-Shock Effects, ITR-1426 (considered final). Project Officer: J.J. Meszaros.

The objective was to provide instrumentation, electronic and self-recording, for obtaining air-blast and ground-shock loading and response of the structures employed by the various structures projects. Included was installation of transducers, recording of transducer signals, and presentation of the recordings as nonlinearized, time-dependent plots of the measured variable in the specified appropriate units. A total of 430 recording channels were utilized; of these 161 were electronic recording on magnetic tape, 225 were self-recording time-dependent gages, and 44 were peak indicating.

A basic description of the instrumentation employed by the Ballistic Research Laboratories during Operation Plumbbob in taking these structural measurements for Projects 3.1, 3.2, 3.3, 3.6, 30.1, 30.2, 30.3, 31.4, and 31.5 is given in ITR-1526. Self-recording gages for measuring peak pressures, pressures versus time, dynamic pressures versus time, and displacement versus time are described; electronic gages for obtaining time-dependent records of pressure, dynamic pressure, acceleration, displacement, and earth pressure are described.

For each type of gage, details are given on the recording mechanism, transducer element, gage mount, calibration, and data presentation. Also, a plot of the field layout is shown.

A tabulation indicating the general success of the instrumentation recording operations and a discussion of anomalies is presented. Finally, recommendations for more effective instrumentation practices are listed.

A.3.8 Project 3.8. Agency: U.S. Army Engineer Waterways Experiment Station. Report Title: Soil Survey and Backfill Control in Frenchman Flat, WT-1427. Project Officer: T.B. Goode.

Results of a soil investigation in the Frenchman Flat area of the Nevada Test Site to obtain data for underground projects in Programs 1, 3, and 6, on the character and certain physical characteristics of the soil to a depth of 200 feet are described. Determinations of the compaction characteristics of disturbed soil and the modulus of deformation of both undisturbed foundation and compacted backfill soils were major objectives, as it was desired that the backfill around the Project 3.1 structures and inside the Projects 1.4 and 1.7 instrumented holes have the same modulus of deformation as the natural foundation soil.

Data from the field-control and the record samples indicated that procedures used in the field for processing, placing, compacting, and controlling the backfill material were adequate and that the desired conditions were obtained. Tests performed before and after the shot indicated that the water content and density of the natural soil and compacted backfill did not change significantly. Results of the tests of consolidation, constant ratio of applied stress (triaxial), soniscope, and load bearing indicated that the soil modulus of the compacted backfill was about equal to that of the natural undisturbed soil when comparisons were made with similar types of tests.

A.4 PROGRAM 4: BIOMEDICAL EFFECTS

A.4.1 Project 4.1. Agency: Walter Reed Army Institute of Research. Report Title: Effects of Nuclear Detonations on a Large Biological Specimen (Swine), WT-1428. Project Officer: G.M. McDonnel.

The data presented in WT-1428 results from investigation of the effect of nuclear devices on a large biological specimen (swine) in the following fields: injuries caused by the nuclear device, wounds produced by glass missiles as the wounding agent, and radiation studies with exposure to both gamma rays and neutrons.

The pig was chosen as the biological target because this animal approximated the human in cross section (for the radiation study) and had been the subject of previous study during Operation Greenhouse. Furthermore, considerable burn research has been done on the pig. Twelve hundred pigs were used in this medical experiment during Shots Franklin, Wilson, and Priscilla at the Nevada Test Site.

The data obtained is extrapolated, wherever possible, to humans.

Experimental design and the animal studied have been shown to be adequate for this study.

The median lethal dose of nuclear device radiation was shown to be 486 ± 10 rep of gamma rays and neutrons. The radiation syndrome and median survival times were similar to those in previous animal studies.

Wounds and burns in combination with nuclear radiation have been studied at all dose levels. Combined trauma and whole-body radiation results in earlier death and an increase in total mortality.

The living specimen within the radius of the precursor, and in the open, will experience near inevitable mortality from dismemberment or displacement. Foxholes at the same radius protect against secondary blast effects and line-of-sight thermal but not necessarily against ionizing radiation. Battlefield debris outside the precursor region does not produce significant wounds.

Analysis of the fate of a living specimen (human) in various environments was shown to be done best by exposing a test animal along with test gages or devices.

In specimens exposed to the combined injuries from a nuclear detonation, the most frequent bacteriological invaders are Staphylococcus albus, Beta-hemolytic Streptococcus and Pasteurella multocida—organisms originating from sites other than the gastrointestinal tract.

Spleen bone-marrow homogenate was ineffective in reducing the mortality from ionizing radiation.

A new procedure for total leukocyte counts is presented as a method of screening radiation casualties.

Operational concepts affecting the medical evaluation of casualties and the resultant therapy are presented.

A.4.2 Project 4.2. Agency: Aero Medical Laboratory, Wright Air Development Center. Report Title: Evaluation of Eye Protection Afforded by an Electromechanical Shutter, WT-1429. Project Officer: Wayne E. Gulley.

This project's objective was to evaluate a high-speed electromechanical shutter that had been developed as a protective device against flashblindness.

The shutter was tested during five shots by the use of animal and human subjects. The thermal energy incident on the shutters ranged from 0.0347 to 0.1804 cal/cm^2. Illumination incident on the shutters ranged from 13,200 to 120,000 lumens/ft^2. The shutter closure time was 550 ± 50 μsec. Recovery after exposure of visual effectiveness of personnel protected by the shutter was instantaneous and complete, whereas unprotected animals received chorioretinal burns. It was concluded that a shutter of the type tested during this operation offered protection from flashblindness. The electromechanical shutter was sufficiently developed to be incorporated into a goggle for service testing.

A simple relationship is also given for scaling peak photometric illumination against peak thermal irradiance.

A.5 PROGRAM 5: EFFECTS ON AIRCRAFT STRUCTURES

A.5.1 Project 5.1. Agency: Bureau of Aeronautics, Department of the Navy, and United Aircraft Corporation. Report Title: In-Flight Structural Response of an HSS-1 Helicopter to a Nuclear Detonation, WT-1430. Project Officer: J. H. Walls.

An instrumented HSS-1 helicopter was flown in the vicinity of nuclear detonations to measure helicopter response to overpressure and gust and to determine the delivery capabilities of the HSS-1 for antisubmarine warfare as limited by blast effects. Measurements of overpressure and resulting stresses were obtained with the helicopter doors and windows opened and with and without tail-cone reinforcements. Partial coverage of the range of shock front incident angles expected from the detonation of underwater nuclear devices was obtained.

Comparisons are shown of experimental gust response data obtained during these HSS-1 tests with prediction of helicopter gust response made possible by employing a six-degrees-of-freedom analysis of helicopter stability and control characteristics and maneuvering loads. Favorable correlation provides confidence that the analytical methods may be employed to predict the helicopter flying qualities as well as applied aerodynamic loads throughout the range of actual delivery conditions.

Comparison of experimental fuselage stresses with analytical predictions are presented to show the accuracy of the stress analysis methods employed for determination of fuselage response to overpressure. Confirmation of analysis methods for structure most critical for overpressure effects permits establishment of the HSS-1 structural limitations due to blast. These limitations were determined by analysis to be the helicopter design limit maneuvering load factor of 2.67 g and a limit overpressure of 0.71 psi.

The primary objective of the project was achieved to the extent that the critical blast limits of the HSS-1 helicopter were adequately defined for application to the problem of safe escape from underwater nuclear bursts.

A.5.2 Project 5.2. Agency: U.S. Navy Bureau of Aeronautics. Report Title: Structural Response and Gas Dynamics of an Airship Exposed to a Nuclear Detonation, WT-1431. Project Officer: D. A. Gilstad.

Four Model ZSG-3 airships, U.S. Navy Bureau of Aeronautics Nos. 40, 46, 77, and 92, participated during Operation Plumbbob to determine the response characteristics of the Model ZSG-3 airship when subjected to a nuclear detonation in order to establish criteria for safe escape distances for airship delivery of antisubmarine warfare special weapons.

Restrained response data for 0.40-psi overpressure input were obtained during Shot Franklin with the ZSG-3 No. 77 moored tail to the blast. Unrestrained response data for 0.75-psi overpressure input were obtained during Shot Stokes with the ZSG-3 No. 40 free ballooned, tail to the blast, 300 feet aboveground.

The first airship exposed to overpressure experienced a structural failure of the nose cone when it was rammed into the mooring mast, together with a tear of the forward ballonet which necessitated deflation of the envelope. The second airship broke in half and crashed following a circumferential failure of the envelope originating at the bottom of the envelope, forward of the car. Neither airship experienced any other failure, except for damage to tail-assembly movable-surface stops from shock forces on the control surfaces. The two other project airships, Nos. 46 and 92, were torn loose from their mooring masts at the Nevada Test Site by high-intensity winds and were destroyed before participating in any shots.

In general, operation with airships within the Nevada Test Site was found to be extremely hazardous because of extreme variations in atmospheric conditions.

Histories of airship response versus time from oscillographic recording are presented for Shot Franklin. for Shot Stokes, overpressure input versus time from oscillographic ground-station recordings is presented. Unfortunately, no airborne oscillographic recordings were obtained during Shot Stokes because of a power failure.

Primarily because of operational difficulties in the field, the scope of the data obtained was not adequate to satisfy the basic objectives of Project 5.2. However, the test results are considered to be a suitable basis for further analytical studies of airship response to nuclear blast effects beyond the scope of this report.

A.5.3 Project 5.3. Agency: U.S. Navy Bureau of Aeronautics. Report Title: In-Flight Structural Response of FJ-4 Aircraft to Nuclear Detonations, WT-1432. Project Officer: A. N. Julian.

Project 5.3 participated in Operation Plumbbob to: (1) measure thermal and blast response of the FJ-4 aircraft to nuclear explosion effects; (2) correlate experimental response data with the analytical predictions to confirm the delivery capability of the FJ-4 aircraft; and (3) obtain data to improve the methods of predicting the blast response of swept-wing aircraft.

Two aircraft, a primary and a standby, were flown during the operation. Provisions were included for identical instrumentation in the two aircraft. This instrumentation provided for the acquisition of data on thermal input and response of thin-skin and honeycomb structures, nuclear effects, overpressures, dynamic response, engine response, and chordwise pressure distribution over the swept wing.

Instrumentation included strain gages, thermocouples, calorimeters, radiometers, pressure transducers, film badges, and pitch-rate and attitude gyros.

The aircraft participated in seven shots, ranging in yields from 10.3 to 74.1 kilotons. The only damage sustained was the blistering of the neoprene rain-erosion coating on the nose radome during Shot Hood.

From the final analyses of the test data the following conclusions were made: (1) correlation of radiant exposure data indicated that shielding affects the thermal output of the nuclear device; (2) the methods for predicting the thermal response of both thin-skin and honeycomb panels to known radiant exposure and irradiance from a nuclear detonation are satisfactory; (3) the critical dynamic response of the aircraft structure was determined to be bending at Wing Station 17.5; (4) the maximum stress levels at Wing Station 17.5 and the maximum amplitudes of aircraft rigid-body pitching motion were accurately predicted, with the former having an average error of only 2.55 percent of limit-allowable stress; (5) for the high-blast incidence angles experienced in this operation, the blast effect and rigid-body response were both nearly proportional to free-stream overpressure and blast-incidence angle; (6) there was a discernible diffraction pulse of force on the FJ-4 wing during blast impingement, however, this pulse had a negligible effect on the critical stresses of the FJ-4 wing; (7) correlation of gamma doses was satisfactory when shielding was taken into consideration; (8) the correlation of postshot free-stream overpressures and times of shock arrival with measured values was excellent; and (9) no power-plant structural damage or adverse operational effects occurred.

A.5.4 Project 5.4. Agency: U.S. Navy Bureau of Aeronautics. Report Title: In-Flight Structural Response of the Model A4D-1 Aircraft to a Nuclear Explosion, WT-1433. Project Officer: J. H. Walls.

This report presents the results of the participation of two A4D-1 aircraft in Operation Plumbbob as Project 5.4.

The objectives of this project were to: (1) measure thermal and blast gust response of the A4D-1 aircraft to nuclear explosion effects, (2) obtain data to improve the methods of predicting blast gust response of aircraft with wings of triangular planform, and (3) correlate experimental response data for the A4D-1 with analytical methods for use in determining its nuclear weapon delivery capability.

The A4D-1 aircraft is a single engine, modified delta wing, carrier-based attack aircraft with capability for delivery of special weapons covering a wide range of weapon yields.

The A4D-1 aircraft, as Project 5.4, participated in seven shots: Boltzmann (11.5 kt), Priscilla (36.6 kt), Hood (71 kt), Diablo (17.0 kt), Shasta (16.5 kt), Doppler (10.7 kt), and Smoky (44 kt).

Since improvement of analytical methods of calculating gust response was the primary objective, instrumentation emphasis was placed on measuring wing pressure distributions, wing shears, moments, torques, and aircraft accelerations. Instrumentation was also installed to measure thermal energy received at the aircraft and the temperature response in the thin skin panels on the lower surface of the aircraft. Additional instrumentation was installed to measure and record time of shock arrival, overpressure, and the effect of the shock wave on engine performance.

The gust response results of the tests are presented as wing chordwise and spanwise pressure distributions versus time, spanwise plots of wing section lift coefficient, average pressure, and center of pressure versus time, aircraft center of gravity and tail acceleration versus time, aircraft pitching motion versus time, wing shear, torque, and bending moment versus time, and tail load versus time. Other results of the tests are presented as irradiance and radiant exposure versus time, temperature in thin skin areas versus time, maximum temperature rise at each thermocouple location, peak overpressure, and time of shock arrival.

Calculated weapon effects and aircraft responses are compared with the measured results to show the adequacy of the analytical methods. For gust responses, the calculated aircraft response used for comparison with the measured results reflects refinements in the analytical methods not included in pretest prediction of gust response. Primarily, the refinements needed to improve the gust response prediction methods were the inclusion of mass coupling effects in the analysis of wing vibration and a change in time duration of the shock diffraction loading. The resulting method of dynamic structural analysis provided analytical solutions which compared favorably with the experimental results.

The prediction methods presented in this report for the thermal effects gave fair agreement with the measured results for the radiant exposure and maximum temperature rise. From comparison of calculated and measured temperature rise using the measured radiant exposure, it is shown that the temperature rise in critical skin panels can be calculated with reasonable accuracy. The principal improvement of the maximum temperature rise calculation appears to be in increasing the accuracy of estimating the radiant exposure.

Excellent agreement was obtained between the measured and calculated peak overpressure and time of shock arrival.

A.5.5 Project 5.5. Agency: Wright Air Development Center. Report Title: In-Flight Structural Response of an F-89D Aircraft to a Nuclear Detonation, WT—1434. Project Officer: G. Stalk.

The primary objective of Project 5.5 was to determine the structural response of the F-89D aircraft in flight to the blast and thermal effects of a nuclear detonation. The recorded data will be used to correct or verify the F-89J Weapons System Capability Study and to further define the F-89J weapon-delivery capability. Use of the F-89D test aircraft to evaluate the F-89J analysis was valid because of the structural similarity of the two models.

To accomplish the objective, the test aircraft was instrumented to measure the overpressure, gust (dynamic-pressure wave), and thermal inputs together with the aircraft response to these inputs. The aircraft was positioned at predetermined points in space in the vicinity of nuclear detonations. The positions selected were not necessarily representative of delivery maneuvers but were at points where the combination of dynamic loads and steady state loads would approach the design limit load.

For each shot except John the aircraft was positioned to receive a high response on the most critical structural member for the particular orientation and gross weight used without exceeding the 5 rem-per-mission limit for maximum nuclear radiation exposure to the aircrew. The range of maximum structural response was 70 to 100 percent of design limit load. In all events except Shot John the aircraft was positioned at various slant ranges from ground zero and was flying in a steady-state 1.0 g level flight condition at shock arrival. On Shot John authorization was granted to exceed the 5 rem-per-mission limit but remain within the 35-rem-total accumulated dosage for the aircrew participating in this event. Shot John was a delivery of an air-to-air weapon (MB-1), containing a nuclear warhead, from an F-89J aircraft with the Project 5.5 F-89D aircraft flying side-by-side formation. At the time of launch, the Project 5.5 aircraft and the delivery aircraft banked in opposite directions performing a typical escape maneuver as determined by the F-89J capability study.

The aircraft successfully participated in 14 events with yields ranging from 0.1 kt to 74.1 kt. Maximum nuclear dosage received by the aircrew occurred in Shot John where the pilot received 3.55 rem and the project flight engineer received 2.44 rem. The maximum free-stream overpressure measured was 0.51 psi during Shot Shasta and the maximum gust loading occurred during the Shot Boltzmann participation where 84 percent design limit load was recorded at Wing Station 267.

From the participation of the F-89D aircraft in Operation Plumbbob, it can be concluded that the response of the F-89J to the blast associated with a nuclear detonation produces higher wing loads than predicted analytically by Northrop Aircraft, Inc. in "F-89J Weapons System Capability Study"; Phase II, Volume I, Summary, NAI-56-891. Therefore, that report should be corrected to reflect the information obtained by this project.

A.6 PROGRAM 6: ELECTROMAGNETIC EFFECTS

A.6.1 Project 6.1. Agency: U.S. Army Engineer Research and Development Laboratories. Report Title: Mine-Field Clearance by Nuclear Weapons, WT—1435. Project Officer: F.E. Deeds.

The objective of the project was to investigate the behavior of pressure-activated antitank mines under airblast loading from a nuclear detonation. Of particular interest were the reliability of current methods for predicting probability of land-mine actuation from nuclear detonations, the effect of burial depth on mine actuation, and the effect of sympathetic actuation in extending the range of mine clearance. In addition, a study was initiated to determine if special methods were needed for prediction of mine actuation at particular ranges of transition in the pressure-wave shape.

Fifteen mine types, both United States and foreign, were employed. Test results indicated: (1) the procedures for predicting mine actuation under nuclear detonations were reasonably accurate; (2) in the live mine fields, sympathetic actuation occurred among mines; (3) the response of the Universal Indicator

Mines (UIM) increased with burial depths to a maximum value between 6 and 9 inches; and (4) the reliability of the actuation curves can be improved by laboratory testing of adequate sampling of mines.

Included within the project were four subprojects conducted by or for Picatinny Arsenal, Diamond Ordnance Fuze Laboratories (DOFL), Chemical Warfare Laboratory (CWL), and the United Kingdom.

The purpose of the study by Picatinny Arsenal was to evaluate the effectiveness of two experimental actuation devices, High Hat and Partner, in providing pressure-actuated mines with protection against blast effects of nuclear detonations. It was concluded that High Hat provided significantly improved resistance to clearance and warranted further development. Although Partner worked well at high overpressure, it was concluded that the value of the design was questionable at pressures less than 16 psi.

Chemical Warfare Laboratory attempted to determine qualitatively the ground contamination pattern produced by E-5 land mines detonated by a nuclear blast. Two mines were detonated by Shot Priscilla. Preliminary inspection showed that the contaminant was spread to a distance of 5 yards from the mine detonation. Analysis indicated a difference in the distribution of ground contamination patterns between mines detonated by the nuclear blast and those detonated individually prior to the test. Dust storms that followed the explosion may have been responsible for the observed difference.

A special program was instituted to test four British mines under conditions specified by British authorities. The objective was to supplement current British data on the behavior of these mines under nuclear-blast loading. A cursory examination was made after the blast to determine: (1) displacement of mine by blast, (2) damage to the mine body, and (3) functioning of the fuzes. Analysis was performed by the British, and the results determined were not a part of Project 6.1.

A.6.2 Project 6.2. Agency: Diamond Ordnance Fuze Laboratories. Report Title: Measurement of the Magnetic Component of the Electromagnetic Field Near a Nuclear Detonation, WT-1436. Project Officer: P. H. Haas.

The magnetic component of the electromagnetic field generated by several nuclear detonations during Operation Plumbbob was measured at distances ranging from 650 to 14,400 feet from ground zero. The output from low-impedance, shielded-loop antennas was amplified, in some cases integrated, and then recorded on magnetic tape by specially designed, ruggedized, and well-shielded tape recorders.

Oscillographic representations obtained from the tapes upon playback include records of field intensity versus time and the time derivative of field intensity versus time. It was determined that the major component of the field is in the azimuthal direction H_ϕ, and that relatively strong vertical and radial fields also exist. Initially sharply rising fields, lasting no longer than 100 msec are followed by longer presistence signals with rise times of millisecond order.

A.6.3 Project 6.2a. Agency: Diamond Ordnance Fuze Laboratories. Report Title: Effect of Nuclear Radiation on Semiconductor Devices, WT-1489. Project Officer: P.H. Haas.

A total of 350 transistors and semiconductor diodes, including germanium and silicon types, were exposed to nuclear detonations. Some of the transistors were operational during exposure as oscillators, amplifiers, and trigger circuits. Radiation levels varied from 10^{11} to 4×10^{14} NVT (n/cm^2) integrated neutron flux, accompanied by gamma radiation between 0.1 and 100,000 r.

The transistors showed a decrease in common-emitter current gain (beta) and an increase in collector-diode reverse leakage current (I_{CO}). The higher-frequency transistors were less affected by neutron fluxes than were the audio units, and the surface-barrier types were virtually undamaged by the maximum fluxes obtained. Semiconductor diodes showed an increase in forward resistance and a decrease in back resistance, with point-contact types showing much less change than the junction types.

Transistors and diodes in operating equipment suffered permanent damage comparable to those passively exposed. Degradation of performance of this equipment was almost entirely attributable to changes in the semiconductor parameters.

The results obtained are in reasonable agreement with data obtained from pile-type reactors, indicating that total integrated neutron flux is of primary significance, rather than rate of exposure.

A.6.4 Project 6.3. Agency: U.S. Naval Air Development Center. Report Title: Attenuation of Electromagnetic Radiation Through an Ionized Medium, WT-1437. Project Officer: William S. Lee.

The objectives of Project 6.3 were to measure the attenuation of electromagnetic radiation of various frequencies due to propagation through an ionized cloud and to compute the rate of removal of electrons by recombination and attachment from the attenuation measurements.

Radio signals propagated through an ionized cloud for yields up to 9.6 kt, from one to four minutes after the detonation, were not attenuated.

An M-33 X-band fire-control radar skin-tracked an FJ aircraft through the ionized cloud created by a 40-kt detonation. No difference in signal level was noted whether or not the ionized cloud was interposed between the radar and the aircraft.

A.6.5 Project 6.4. Agency: Air Force Cambridge Research Center. Report Title: Accuracy and Reliability of a Short-Baseline Narol System, ITR-1438 (considered final). Project Officer: Richard A. Houghten.

The primary objectives of this Indirect Bomb Damage Assessment (IBDA) experiment were to incorporate results of Operation Redwing into an operational-type short-baseline Narol system and to study the reliability and accuracy of the system as a function of yield, range, type of propagation paths, and lightning-transient interference.

Narol nets, each consisting of two unmanned slave stations and one manned master station, were established at Albuquerque, New Mexico, Vale, Oregon, and Rapid City, South Dakota. Forty-three lines of position (from a possible 49) were obtained having average errors of 0.5 nautical miles for the Albuquerque net, 0.4 nautical miles for the Vale net, and 0.8 nautical miles for the Rapid City net. These lines of position gave fixes having an average error of 0.8 nautical miles. In general, the times of detonation were measured with an error of less than 10 milliseconds.

Lightning transient data were recorded and analyzed throughout the test series at various times of the day. In general, it was found that there were no consistent patterns peculiar to the waveforms, field strengths, or pulse durations of these transients that would distinguish them from the electromagnetic pulse of a nuclear detonation.

To speed data reduction and analysis, an area-gating system was tested. With this system, the film records of electromagnetic transients originating within a 10-mile radius of the detonation were marked electronically, thereby reducing the amount of data that had to be analyzed.

The area-gating system was tried on six shots. On each, data were collected for about one-half hour, and the area-gating system correctly marked the record for concurrent identification and analysis. With the record so marked, operators were able to select the correct pulse, analyze it, and report the fix and detonation time in less than fifteen minutes.

A.6.6 Project 6.5. Agency: White Sands Missile Range. Report Title: Effects of Nuclear Detonations on Nike Hercules, WT-1439. Project Officer: G. E. Elder.

The effects of nuclear-warhead detonation on the performance of the Nike Hercules guided-missile system were investigated.

The primary objective was to determine the effects of neutron and gamma irradiation on the performance of the guidance system. The production-type vacuum-tube model, the experimental transistorized model, and selected components were exposed during Shots Wilson, Owens, and Morgan. Selected components were exposed during Shot Fizeau.

Propellants and warhead system components were exposed during Shots Owens, Morgan, and Fizeau. In general, the components showed no sensible deterioration of effectiveness.

A second objective was to investigate the effects of nuclear-warhead detonation on the propagation of radar signals. Measurements were made on Shots Boltzmann, Franklin, Lassen, Hood, and Kepler. These measurements indicated that the signals are attenuated and reflected to a degree which merits a more comprehensive study of this problem. Results are inconclusive for application to the effects which might be experienced at high altitudes.

A.7 PROGRAM 8: THERMAL RADIATION AND EFFECTS

A.7.1 Project 8.1. Agency: U.S. Army Quartermaster Research and Engineering Command. Report Title: Thermal Protection of the Individual Soldier, WT-1440. Project Officer: Frank H. Babers.

The objectives were to evaluate in the field, under the conditions of an actual nuclear detonation, the performance of clothing and other items developed for the protection of the individual soldier and to provide assistance to the personnel of Project 8.2 in an investigation of the feasibility of using a skin simulant as a substitute for animate skin in studying weapon effects.

The items developed to provide thermal protection for the soldier included two experimental hot-weather uniform ensembles, three shielding materials, a protective cream, and a three-layer flashoff-reflector-insulating system. These were exposed during Shot Priscilla to anticipated thermal energies varying from 10 to 25 cal/cm^2, together with appropriate controls, while using white-skinned pigs as test subjects.

Both experimentally designed uniform ensembles provided considerably greater protection than did the control. These experimental uniforms were similar with respect to their outer layer, fire-resistant-treated cotton poplin, and a cotton tee-shirt underlayer. They differed with respect to their middle layer, one using a light-weight 50-50 wool-cotton fabric and the other a fabric designed to separate the inner and outer layers. Of these, the uniform containing the spacing fabric was considered the most effective in preventing burns, for eight of the twelve animals exposed at the three stations were judged to have received essentially no burns, and large-area burns were no more than 1+. However, all uniform assemblies were so damaged at all exposure levels as to be judged functionally unsuitable.

The three shielding materials tested were: (1) a light-weight cotton poplin, 5 oz/yd^2, fire-retardant treated; (2) an 8.5 oz/yd^2 sateen; and (3) neoprene-coated Fortisan poncho material. The shields were positioned 6 inches in front of clothed animals with bare skin areas and subjected to radiant exposures of 14.5 and 24 cal/cm^2. The poncho material and the fire-resistant poplin prevented damage to the uniform ensemble and reduced the bare-skin burns from 5+ on unshielded animals to spotty 1+ and 2+ burns. At 24 cal/cm^2 of exposure, the sateen shield offered little or no protection to the animal or uniform, but gave some protection at the 14.5-cal/cm^2 station. All shielding materials were destroyed, but the efficiency of the shielding principle was demonstrated.

An experimental thermal protective cream, QMC 305-X and a three-layer flashoff-reflector-insulator system showed excellent protective qualities when subjected to radiant exposures of 14.5 and 24 cal/cm^2.

The Naval Material Laboratory conducted a skin-simulant study in conjunction with the QMC project and provided the project with data as to the calorie levels produced at each station. The results of this test will be given in the final report of Project 8.2 (Naval Material Laboratory).

It is considered that the overall objectives of the test were met successfully.

A.7.2 Project 8.2. Agency: Naval Material Laboratory. Report Title: Prediction of Thermal Protection of Uniforms, and Thermal Effects on a Standard-Reference Material, WT-1441. Project Officer: W. L. Derksen.

The purpose of Project 8.2 was to determine the adequacy of the laboratory methods employed in the study of the effects of intense thermal radiation on materials. The primary objectives were to determine the adequacy of physical methods for studying thermal damage to materials and for evaluating, by means of a physical skin simulant, the protection afforded by clothing to personnel against intense thermal radiation. A secondary objective of the project was to compare the burns predicted from the temperatures of the skin simulant behind an irradiated fabric assembly and the burns obtained on animals under identical exposure configurations. Project 8.2 made basic thermal radiation measurements for the use of Projects 4.1, 8.1, and 8.2.

The skin-simulant study involved a major participation at stations which received radiant exposures of 6.5 and 15.5 cal/cm^2 during the Shot Priscilla (36.6 kt) detonation and at a distance corresponding to a radiant exposure of 16.2 cal/cm^2 for the Shot Hood (71 kt) detonation. Project 8.2 also made supporting measurements during Shots Lassen and Wilson. Representative cellulosic materials were exposed during Shot Priscilla at stations corresponding to radiant exposures of 6.5, 8.5, 10, 13, 15, and 21 cal/cm^2 to determine whether the threshold ignition energies of these materials determined under field conditions verify the data predicted from laboratory studies. Basic thermal radiation measurements were made during Shots Lassen, Wilson, Priscilla, and Hood.

The results of this field experiment indicate good agreement between temperatures measured in the field and temperatures predicted by laboratory methods employed in thermal radiation studies. The exceptions were that the laboratory experiments would predict higher temperatures for 3.5 and the 7.5-cm-diameter areas for exposures for which cloth would be expected to ignite than those which were measured in the field experiment. Blast effects are postulated to account for this difference.

In three of the four situations for which postshot data were available, the skin simulant adequately predicted burns to pig skin exposed in similar exposure geometries.

Measurements of thermal radiation were made successfully, and showed reasonable agreement with the generalized pulse except for a slightly higher irradiance after the irradiance maximum for Shots Priscilla and Hood.

A.7.3 Project 8.3a. Agency: U.S. Naval Radiological Defense Laboratory. Report Title: Performance of a High-Speed Spectrographic System, ITR-1442 (considered final). Project Officer: William B. Plum.

A high-speed streak spectrographic system with a time resolution of about 100 μsec, which is the prototype of the instrumentation to be used for obtaining early-time spectra of bomb light during Operation Hardtack, has been field tested. The results obtained were highly satisfactory, especially with regard to sensitivity at low light levels. The results indicated good possibility for obtaining spectra with reasonable optical density during Operation Hardtack.

A.7.4 Project 8.3b. Agency: Wright Air Development Center. Report Title: Instrumentation for Measuring Effects Phenomena Inside the Fireball, WT 1443. Project Officer: Charles J. Cosenza.

Part 1. This project exposed specimens within or near the fireballs of Shots Priscilla (36.6 kt) and Smoky (44 kt) to proof-test experimental instrumentation systems and to achieve more detailed information concerning the thermomechanical effects of a nuclear detonation, with an ultimate objective of determining the structural vulnerability of intercontinental ballistic missiles. This work is related to previous participations by Project 5.4 of Operation Teapot and Project 5.9 of Operation Redwing.

Of the 25 specimens exposed, four contained time-history instrumentation consisting of an eight-channel magnetic tape recorder with strain gage and thermocouple transducers. Mechanical instrumentation included peak-pressure gages in four specimens, velocity-distance impact gages in five specimens, and thermal intensity gages in eight specimens. Four specimens were specifically designed as carriers for inserts of various materials including ceramics, metals, and polymers. Nine spheres of various materials were exposed to obtain additional ablation data. In addition, one solid graphite sphere was exposed to determine the effects of neutron bombardment. For Shot Smoky, 24 of the specimens were exposed at ranges from 150 feet to 1,380 feet from the burst point. The majority of the specimens were suspended from cables extending from the shot tower to deadmen.

Of the 25 specimens exposed, 24 were recovered. The high radiation level after Shot Smoky delayed the major recovery effort for approximately 5 months. The tape transport system from two of the five tape recorders operated satisfactorily; the recording tape supply had been exhausted. One recorder operated successfully through time zero but was subsequently damaged from lateral acceleration, and the tape was severely damaged from excessive heat. One recorder operated momentarily, moving the tape approximately $^3/_8$ inch. The exact cause of failure has not been determined. The recorder exposed during Shot Priscilla operated a short time before the tape wrapped around the pinch roll, subsequently jamming the recorder. Of the three tapes that yielded signals during the time of interest, one tape provided four channels of information that could reasonably be construed as transducer outputs. Consideration of several factors involved in the data reduction process, however, casts some doubt on the amplitude validity of this data.

Transistor oscillators of the type employed in the instrumented specimens are not capable of operating satisfactorily at a slant range of 350 feet or closer for a yield similar to that of Shot Smoky. Strain-sensitive transducers employing bonded wire strain gages are capable of being exposed inside the fireball of a nuclear detonation without an appreciable change in the calibration factor at a slant range of 350 feet or greater with exposure conditions and yield similar to those for Shot Smoky. It is believed that the state of the art of recording fireball phenomena was advanced as a result of this test; however, it is believed the art of recording is not sufficiently advanced at this time to obtain usable data at a slant range of 160 feet or closer for a yield similar to that of Shot Smoky, using the instrumentation techniques employed during that shot.

Three specimens instrumented with velocity-distance impact gages yielded apparently reliable velocity versus distance data and, subsequently, specimen acceleration versus time data.

The Haveg Rocketon and plastic materials provided adequate thermal protection for the tape recorders located in the electrically instrumented (EI) cylinder at a slant range of 160 feet during Shot Smoky. The plastic shell and materials provided adequate thermal protection for the tape recorder located in the EI steel sphere, Type 3, at a slant range of 350 feet during Shot Smoky. The reduction in radius of the spherical plastic shell surrounding the EI steel sphere, Type 3, was approximately $2^1/_2$ times the reduction in radius of a solid steel sphere of comparable size and weight located at the same range. Both spheres were exposed at a slant range of 350 feet during Shot Smoky.

Part 2. An account is given of ablation and pressure measurements within the fireball of Shot Smoky. The ablation specimens were spheres of plastic, steel (some clad in plastic), or zinc; many of these surfaces contained cylindrical plugs of various test materials. Peak pressures were measured by ball-crusher gages. Two sets of gages of different response time were mounted side by side in each steel sphere.

Two events partially obscure the results: as a safety measure in the field, the specimens were wrapped in nylon slings, considerably decreasing ablation; furthermore, fireball plasma spikes swept down the specimen support cables and over the specimens ahead of the main fireball, modifying the pressure-time history.

It was discovered that the plastic was ablated much more than in any previous test; further controlled tests are needed to resolve this important anomaly. Other conclusions are that the vapor-shield theory of plastic ablation is given some indirect confirmation, that the ablation of metallic bodies is extremely sensitive to immersion time, and that a small addition of plugs of low-ablating metal to a surface of high-ablating metal will partially protect the surface.

The measured peak pressures agree to within a factor of three of theoretical predictions based on a simple model, using the numerical solution of a spherical blast wave given in H. L. Brode's "Numerical Solutions of Spherical Blast Waves"; Journal of Applied Physics, June 1955, Vol 26, No. 4, Pages 766 - 775. The pattern in which calculated peak pressures deviate from theory provides the first direct evidence that the pressure input to a body immersed in a fireball spike is significantly different from that in the main fireball—the pressure probably decaying less rapidly with time at a point engulfed by a spike. As in Shot Erie of Operation Redwing, there appear to be sharp, localized fluctuations in measured peak pressure over comparable regions of the same sphere.

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